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Japanese Reports on Electrical Fire Causes

Summarized and translated by Yasuaki Hagimoto (NRIPS Japan)
visiting VTT from 14 Feb. 1996 to 12 March 1996

Note: Figures in ( ) denote the number of sheets in Japanese.

1(19). Investigation Reports and Igniting Experiments on the Electrical Causes of Many Fires Started after the Big Earthquake in Kobe Area in 1995

K. Kinoshita, Y. Hagimoto, N. Watanabe
This report is a part of "Urgent Study Reports on the HanshinAwaji Big Earthquake, the Science and Technology Agency of Japan, June 1995"

Abstracted by translator

People were evacuated from their houses after the earthquake. Some of the fires started from their houses just after the electrical power supply was resumed.

In the ignition experiments, electric wires were connected to the power supply through two types of circuit protection devices. One protection device is a popular type equipped with thermal cutting out mechanism and the other protection device, which has thermal and electromagnetic mechanism, is not a popular type because it is a little more expensive the former. And a short circuit was made on the combustible materials. The combustible materials used in the experiments were cotton in the quilt for use as a Japanese bed, cotton gauze, and newspapers. The wires were crossed in two different angles, 10 and 90 degrees. Peak value of the current, electrical energy of the arcing, time needed to cut off the circuit, etc., were measured.

2. Glowing Phenomenon at the Contact of Different Kind of Metals

Y. Hagimoto, K. Kinoshita, T. Hagiwara
Summary of Annual Meeting of Japan Society for Safety Engineering

Abstracted by translator

Copper wire, brass wire and iron wire were used in all combinations. DC 100V and AC 100V power supply were used. The electrical energy at the glowing contact was measured. The energy at the contact and their increasing rate were compared.

Tanslation begins here

1 Introduction

A loose connected contact sometimes results in "glowing contact" which cause abnormal heat.(ref. 1, 2) This experiments were carried out to examine the electrical characteristics at the contact of different kind of metals.

2 Method of experiments

Experimental arrangement is shown in figure 1. Copper, brass and iron were used for this experiment in every combinations (Cu-Cu, Cu-Fe, Fe-Fe, Fe-Br, Br-Br and Br-Cu). These contacts were connected to DC 100 V or AC 100V and variable resistance in series. 'ON and OFF' at the contact was repeated until glowing started.

3 Results of experiments

1) Similarity of these phenomena

Wave forms of the AC voltage across the contacts of every combination shown in figure 3 were similar to that of Cu-Cu contact.

In case of any combination of metals, glowing path, where current flows, was observed on the glowing part between two metals.

2) Component of the glowing part

Major component of the glowing part are shown in table 1. This table shows that these parts are the oxidized metal connected to (+) pole of the power source.

Table 1 Major component of the glowing part (analyzed by X-ray diffraction)

AC / DC	Combination of metals	Component
AC	Cu - Cu	Cu_2O, CuO
DC	Cu (+) - Br (-)	Cu_2O, CuO
DC	Cu (+) - Fe (-)	Cu_2O, CuO
AC	Br - Br	ZnO, Cu_2O, CuO
DC	Br (+) - Cu (-)	ZnO, Cu_2O, CuO
AC	Fe - Fe	Fe_3O_4, Fe_2O_3
DC	Fe (+) - Cu (-)	Fe_3O_4, Fe_2O_3

3) Electrical characteristics

Wave forms shown in figure 3 indicates that the contact of the conductor metal and oxidized metal (glowing part) has rectifying characteristics.

DC voltage across various contacts are shown in figure 4. (Horizontal axis is time (minutes) and vertical axis is voltage (V). Japanese letters in the figure are as follows.)

Cu(+)-Fe(-) Cu(+)-Br(-)
Cu(+)-Cu(-)

a. (+) pole is connected to copper.

Br(+)-Cu(-) Br(+)-Fe(-)
Br(+)-Br(-)

b. (+) pole is connected to brass.

Fe(+)-Cu(-) Fe(+)-Br(-)
Fe(+)-Fe(-)

c. (+) pole is connected to iron

Fig. 4 Transition of DC voltage drop across the contact

4) Electrical heating

Transition of DC voltage in case of DC 2A shown in figure 4 are gathered in figure 5. It shows that the voltage drop across the contact depends upon the kind of metal connected to (+) pole.

Electrical energy dissipated at the contact on hour after the starting of glow are shown in figure 6.

5) Breeding speed of the glowing part

Cu: several mm / hr

Br: 1/10 of several mm / hr

Fe: negligible

Breeding speed of copper connected to (+) pole has a maximum value at 6 Amps as shown in figure 7.

6) Fire hazard

Iron starts glowing more easily than copper or brass. But the electrical energy dissipated at the glowing copper oxide or brass oxide is larger than that dissipated at the glowing iron oxide as shown in figure 4.

This phenomena can hardly be found until a fire starts because the voltage drop at the contact is only several Volts and most electrical appliances are not affected by it.

Small current (AC 0.5A) can start this phenomena and the maximum temperature at the glow, although which is very small, will exceed 1000 C.

3. Phenomenon of Glow at the Electrical Contacts of Copper Wires

Y. Hagimoto, K. Kinoshita, T. Hagiwara
NRIPS (National Research Institute of Police Science) Reports- Research on Forensic Science -, Vol. 41, No. 3, August 1988

Abstract

A series of experiments were carried out to study the phenomenon of the glow at the contacts of copper and to find the current condition of practical use in the electrical fire investigation. In these experiments, the contacts of copper wires connected to AC or DC power source and a variable load resistance in series were used. The results are as follows:

1) Average DC power dissipated at the contacts of wires 1 mm in diameter was almost constantly 16 W in the range over 2 A. Average AC power dissipated at the contacts of wires 2 mm in diameter was almost constantly 28 W in the range over 5 A.

2) For 1 mm wires, the maximum breeding speed of Cu_2O was 17 mm/hour with 2 A AC, and 18 mm/hour with 2 A DC, For 2 mm wires, the speed was 6 mm/hour with 2.5 A AC, and 12 mm/hour with 5 A DC.

3) For 1 mm wires, the ranges of the current necessary for the glow to continue were 0.3 - 2 A AC and 0.3 - over 8 A DC. For 2 mm wires, they were 1 - 2.5 A AC and 0.5 - over 8 A DC.

4) The upper limit of these ranges of current were affected by the spattering caused by the glowing contacts.

1. Introduction

Heat generated at an electrical poor contact is one of the causes of a fire. This poor connection sometimes results in glowing contact (ref. 1, 2, 3). If the glowing at a contact of copper wires are left, oxidized part, which contains mainly Cu_2O and is called "hot zone" (ref. 4), expands (see figure 1). As the flow of current is concentrated due to the temperature-resistance characteristics of Cu_2O, temperature of the current path become high and the path glows. Temperature of the "glowing path" is considered to be in excess of melting point of Cu2O because wavy traces are observed on the surface of hot zone. Typical voltage drop across the hot zone and AC current of this phenomenon is shown in figure 2. Fire hazardous aspect of this phenomenon is that it can be started with small current such as 1A and it can not be noticed because of small voltage drop.(ref. 5-8)

This study was made to know more about the heating mechanism of glowing path and the expanding process of the hot zone at the contact of copper wires.

2. Experiment

Experimental arrangement used for this study is shown in figure 3. The gap of two copper wires was controlled by a micrometer. The diameter of the copper wire is 1 mm or 2 mm. Both DC power source and AC power source were used.

Output voltage of the DC power source was kept 100V by the adjust of resister, R_1. DC voltage drop across the hot zone was recorded by a DC voltage recorder.

AC current was kept constant by adjusting R_1. AC current was measured by moving-coil-type ampere meter because it was almost sine wave (see figure 2).

Voltage drop across the hot zone ("v" shown in figure 3) and current ("-i" shown in figure 3 which was calculated from the voltage drop across R_2 (0.1 or 1.0)) was recorded to digital memory for both DC and AC measurements.

3. Result and Discussion

3-1 Mechanism and characteristics of heating

3-1-1 White heat at the end of glowing path

In case of AC, an incandescent points (,where glowing is extremely strong) were observed at both ends of the glowing path which moves around the hot zone as if it were a worm. This strong glow was observed only when the ends of the glowing path, which seemed to repeat expanding and contracting, reached the boundary between hot zone and non-oxidized copper. Non-oxidized copper at the boundary was oxidized by the strong glow little by little.

In case of DC, the feature of glowing path is almost same as figure 1. But the incandescent point was observed only at the boundary between the hot zone and the copper wire which was connected to (+) pole of the DC power source. The copper wire connected to (+) pole was not oxidized and the hot zone did not expand toward the (+) pole.

3-1-2 Temperature measurement of glowing path

It was observed microscopically that the surface of the glowing path is glossy and it moves like flowing metal. Temperature at the center of the glowing path was measured by K-type thermo-couple o 0.08 mm in diameter. The maximum temperature measured was 1250 C for both AC and DC under the condition of room temperature, 25 C. This temperature is considered to be reasonable in comparison with the melting point of Cu_2O, 1230 C (ref. 7).

This temperature did not almost changed when the AC or DC current was increased or decreased. It is considered that this is due to the following two reasons.

The first reason is that the coefficient of the relation between electrical resistance of Cu_2O to temperature is negative. Increasing current results in decreasing resistance and suppressing the power dissipation in the glowing path.

The second reason is that the cross section area of the glowing path increases when current value is increased. Width of the path which was measured for the copper wire of 2 mm in diameter with DC 1 A, 2 A, 4 A and 8 A were about 0.2 mm, 0.4 mm, 0.8 mm and 1.4 mm respectively. Increasing current results in increasing cross sectional area of the path, increasing electrical resistance of the path and also decreasing the power dissipation in the path.

3-1-3 Examination of glowing heat

(1) Contaminant of hot zone

Two kinds of heat, Joule heat and chemical reaction heat, were examined as the heat source of the glowing path.

At first, the composition of hot zone was analyzed by X-ray diffraction. It was confirmed that the hot zone consists mainly of Cu_2O and CuO but only of Cu_2O below the surface.

Next, the weight ratio of the hot zone to the loss of copper wire was measured. Figure 4 shows the results which were measured 1 2 hours after the stating of the glowing. In the region of small current, this ratio is larger than 1.0 (average is 1.15) because of the increased weight by oxidation. But in the region of large current (over 2A AC and over 6A DC), this ratio is smaller than 1.0 because of spattering (, which is detailed in **3-3**).

Weight ratio of Cu_2O to CuO in the hot zone, which was calculated from the above mentioned ratio (1.15) on the assumption that the hot zone is made only of Cu_2O and CuO, was 81 : 19.

(2) Joule heat and reaction heat

Joule heat generated at the hot zone was obtained from (integrated voltage (v) shown in figure 3) i(constant). Reaction heat generated at the hot zone was obtained from the heat necessary for the formation of Cu_2O and CuO (1.17 kJ/g and 1.95 kJ/g respectively) and the weight ratio of Cu_2O to CuO. The results are shown in figure 5. Reaction heat was found to be negligible in comparison with Joule heat.

3-1-4 Measurement of the Joule heat

Electrical energy (DC current) dissipated at the hot zone (glowing path) during the first one hour (from the starting of glow to one hour later) is shown in figure 6. Electrical energy dissipated at the hot zone between copper wires of 1 mm or 2 mm in diameter was saturated at about 60 kJ or about 100 kJ in the range over 2A or 5A DC respectively. (60 kJ / 3600 sec 16 W, 100 kJ / 3600 sec 28 W)

3-1-5 Electrical characteristics (AC)

Since Cu_2O has electrical characteristics of P-type semiconductor (ref. 10), it was expected that the boundary between copper and hot zone has rectifying characteristics.

AC voltage across the glowing path (v_1, v_2, and v_3 shown in figure 7) was measured. The result is shown in figure 8. ($v_2 + v_3 = v_1$) but the form of (v_2) is different from that of (v_3). If the boundary has ohmic characteristic, the shape of (v_2) and (v_3) should be the same. This indicates that the boundaries at the both ends of the hot zone have rectifying characteristics and they are in reverse each other.

In case of the wave form shown in figure 2, t_2 t_3 and t_4 t_5 is the period of the breakdown of the boundaries, and t_1 t_2 and t_3 t_4 is not the period of the breakdown.

3-1-6 Electrical characteristics (DC)

Voltage distribution along the glowing path was measured by the method shown in figure 9. The results are shown in figure 10. (v_1), (v_2) and (v_3) in figure 10 is correspond to the same symbols in figure 9. It was found that both ends of the path have large voltage drop which cause incandescent glow.

It is estimated that the both ends of the path generate incandescent glow alternately in case of AC.

3-2 Breeding of hot zone

3-2-1 Direction of breeding

It was found that hot zone expands toward both sides in case of AC and toward (+) pole side in case of DC. Therefore, the expansion of the hot zone is the result of the oxidation caused by the incandescent heat at the boundaries.

3-2-2 Measurement of breeding speed

Average expanding speed of the hot zone during the first one hour was measured. The results of the measurement are shown in figure 11.

In case of DC, the profiles showed peak speed at 2 A for the copper wire of 1 mm in diameter and at 5 A for the copper wire of 2 mm in diameter. In the region over these currents, glowing path became fuzzy and the current flow spread, and finally whole area of the hot zone became to glow and the incandescent glow at the end of the path disappeared. This decrease of the expanding speed is due to the spread current.

In case of AC, hot zone could not continue expanding over 2 A for the copper wire of 1 mm in diameter and over 2.5 A for the copper wire of 2 mm in diameter because of the consumption due to spattering from the edges of the glowing path. This spattering will be considered in 3-3-1.

3-3 Current range of glowing

3-3-1 Maximum current and spattering

In case of AC, the maximum currents (2 A for 1 mm copper and 2.5 A for 2 mm copper) which can maintain the glow were limited by the spattering.

In case of DC, the maximum currents exceeded 10 A, but they could not be measured because the DC power source could not supply the current over 10 A.

3-3-2 Cause of spattering

The spatters were detected by a photo-transistor and the signal of the detector was recorded by a digital memory. Copper wires of 2 mm in diameter and 2 A AC current were used for this measurement. Figure 13 (b) shows the detectors output and (a) shows the voltage across the glowing path measured at the same time. Small pulses corresponding the detectors output are observed on (a). The detectors output delayed the pulses on (a) because the spatters need time to go to the detector and to be detected.

It was found that only (+) side of the end of the glowing path spatters.

In case of DC, almost same results as figure 13 are obtained in figure 14.

The mechanism of spattering is considered as follows.

a) Large voltage drop at end of glowing path, where rectifying direction is in reverse, results in a large heat generation.

b) When the temperature of the small area (breakdown area) at the end of the path exceeds the boiling point of Cu_2O, this area is blown off.

c) Then breakdown is ended but it is recovered immediately. This is shown as a pulse in figure 13.

3-3-3 Alternating current and spattering

Two types of currents, (a) and (b) shown in figure 15 which are different only in their flowing direction, are used in this experiment. Spattering with current (b) was fainter than that with (a). The maximum current (rms value) for 2 mm copper wires was 2.5 A in case of (a), but was 5 A in case of (b). In 3-3-1, it was more than 10 A in case of DC. It is supposed that spattering is affected by alternating frequency of current.

3-3-4 Minimum current

The minimum current necessary for maintaining the glowing of 1 mm wire was 0.3 A (both AC and DC), and that necessary for maintaining the glowing of 2 mm wire was 1 A AC or 0.5 A DC. It was found that the minimum current in case of DC is smaller than that in case of AC.

4. Conclusion

Following results were obtained:

(1) The boundary of hot zone and copper wire has rectifying characteristics which is conductive from the former to the latter.

(2) In case of AC, the hot zone expands toward both sides. In case of DC, it expands towards only (+) pole of the source.

(3) Temperature at the center of glowing was about 1250 C. It was caused Reaction heat was negligible in comparison with Joule heat at hot zone.

(4) Electrical energy dissipated at the hot zone between copper wires of 1 mm or 2 mm in diameter was saturated at about 16W or about 28W in the range over 2A DC or 5A DC respectively.

(5) For 1 mm wires, the maximum breeding speed of Cu_2O was 17 mm/hour with 2 A AC, and 18 mm/hour with 2 A DC. For 2 mm wires, the speed was 6 mm/hour with 2.5 A AC, and 12 mm/hour with 5 A DC.

(6) For 1 mm wires, the ranges of the AC or DC current necessary for the maintenance of glowing was 0.3 - 2 A or 0.3 - over 8 A respectively . For 2 mm wires, they were 1 - 2.5 A or 0.5 - over 8 A respectively.

(7) The maximum current which can maintain glowing was affected by spattering from the end of the glowing path.

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4. Igniting Experiments of Flat-type Cables by Dropping Saline Solution on their Damaged Insulation

T. Hagiwara, Y. Hagimoto; J. of Japan Association for Fire Safety and Engineering (JAFSE), Vol. 37, No. 5, (170), 1987

Abstracted by translator

This flat-type cable is used very popularly as the wiring behind the ceiling in Japan. It has two copper wires of 2.0 mm in diameter. Each wires are covered with flexible PVC insulation and they are covered again with the same insulating material. Concentration of salt in the distilled water was changed from 0% to 15% (0%, 1%, 2%, 3%, 5%,7%,10% and 15%). Load of 10 connected in series limited the maximum short current within 10 Amps. Main results are as follows:

a) Much longer time was needed to ignite the cables when the concentration of the solution was decreased below 5%.

b)Although insulating material has self-extinguishing characteristic, the insulating material continued to burn for about 20 minutes while an electrical arcing was generated. This burning was considered to be enough to ignite combustibles nearby.

c) The copper wire with arc marks was analysed by EDX and copper oxide was detected in its surface. (This is not new and quite natural.)

d) Insulating materials carbonised showed high electrical conductivity. It was also analysed by EDX and chloridized copper was detected. (This is also natural.)

5. Temperature Measurements of Extension Electrical Cords Using a Thermal Camera

Y. Hagimoto, K. Kinoshita; Summary of 1992 Annual Meeting of JAFSE
(Detailed in No. 7 and 8)

6. Fire Hazard of a Coiled Electric Cord Insulated with Synthetic Rubber

Y. Hagimoto, K. Kinoshita; Summary of 22th Symposium on Safety Engineering, 1992 *(I do not know the real name in English.)*

Abstracted by translator

Temperature of a coiled cord covered with cloth exceeded 300 C with current of 12.5 Amps. The rubber was carbonised and the cloth started flameless combustion. Electrical energy dissipated in the cord of 200 C is about two times as large as that of 0 C.

Various insulating materials such as chloroprene rubber, neoprene rubber, phenolic resin, uric resin and lauan, a kind of wood, were carbonised in various temperature from 300 to 1000 C. Synthetic rubber showed high conductivity enough to cause short circuit when it was carbonised above 400 C. Other materials carbonised above 700 C showed high conductivity enough to cause short circuit.

These materials were put in a very small case and were heated in a electrical heating box. As they were packed in a very small case, they did not burn and became carbonised in the atmosphere of high temperatures. Low DC voltage was applied to the carbonised material and the DC current flowing through the material was measured. The circuit for this measurement is shown in No. 97. Electrical resistance of the material was calculated from the voltage and the current. figure 2, 3, 4 and 5 shows the relation between the resistance and the current of rubbers, phenolic resin, uric resin and lauan respectively. These figures shows the resistance is low enough to cause an arc discharge if AC 100V is applied to the carbonised materials. If they are used as an insulating material of wiring circuit, they will cause a short circuit.

7 & 8. Fire Hazard of a Coiled or Bundled Cord

7: Y. Hagimoto, K. Kinoshita, N. Watanabe; Summary of 1994 National Convention Record I. E. E. Japan
8: Y. Hagimoto, K. Kinoshita, N. Watanabe; Summary of 1994 Annual Meeting of JAFSE

Abstracted by translator

PVC insulation of an electrical cord with 12.5 Amps current was melted and short circuit was made when the cord is coiled only three times and covered with cloth. The size of this cord was 0.75 mm^2 in area.

Short circuit was made not by man but by electricity. As the cord is exposed to high temperature, the insulation fails by becoming soft and flowing off the conductor.

9 (1), 10(2), 11(1), 13(2) & 14(2). Fire Hazard by Short Circuit due to Arcing between Conductors of Wiring

9: Y. Hagimoto, K. Kinoshita, T. Hagiwara; Summary of 1989 National Convention Record I.E.E. Japan
10: Y. Hagimoto, I. Ishii, K. Kinoshita; Summary of 22th Meeting of Japan Association for Safety Engineering, 1989
11: Y. Hagimoto, K. Kinoshita, Y. Ishii; Summary of 1990 National Convention Record I.E.E. Japan
13: K. Kinoshita, Y. Hagimoto, Y. Ishii; Summary of 1991 Annual Meeting of JAFSE
14: Y. Hagimoto, K. Kinoshita, Y. Ishii; Summary of 1991 Annual Meeting of JAFSE
(Detailed in No. 15)

12(1). Measurement of Temperature at a Terminal Connected to a Wiring Loosely

K. Kinoshita, Y. Hagimoto; Summary of 1990 National Convention Record I.E.E. Japan

15(7). Protection Failure of Short-circuit by Arcing along the Insulating Material between Two Conductors of Wiring or Wiring Devices

Y. Hagimoto
NRIPS, Japan
Journal of Tokyo Electric Management Engineering Association, January 1992.

Abstract written by translator

Fires from electrical cords or from wiring devices are increasing in these years. The reason is supposed to be the increase of electrical power dissipation for domestic use.

A circuit breaker is used to protect the circuit from overcurrent or short-circuit. If the conductors do not touch directly and they are shorten by an arcing along the carbonised insulating material, the current flows intermittently.
This is the reason why a circuit breaker does not cut off the current more than 100 Amps and fire hazardous sparking continues.
Peak value of the short-circuit current is limited by the resistance of the circuit. In typical conditions the circuit breaker does not cut off the intermittent current under about 200 Amps in peak value. This condition is easily made when an extending cord of about 10 meters long is used.

Translaion begins here

1 Introduction

Japan has approximately 60000 fires a year. The number of fires related to electrical cause or electrical appliances are shown in table 1. Although insulating materials have been increased their quality, the number of electrical fires have not been decreased.

Table 1 Statistics of electrical fires in Japan

Year	1980	1981	1982	1983	1984	1985
Total number of fires	59885	59865	63272	58833	59674	55763
Electric heater for cooking		192	193	155	176	190
Electric room heater	363	457	539	511	637	503
Cable for lighting or telephone	800	881	930	944	972	978
Electrical equipments	502	445	471	447	453	489
Electrical appliances					819	713
Wiring devices	398	459	468	450	428	507
Light including neon light	358	321	331	310		
Electric Iron	130	128	94	98		
Others	1659	1564	1582	1590		

note: Blank is due to the change of classification.

2 Electrical fire causes

Electrical fires are caused by heat of poor connection, glowing connection, arc tracking, short circuit, disconnection, overcurrent and so on.

3 Arcing along the carbonized insulating material

Electrical failures above mentioned sometimes result in an arc tracking along the insulating material between two conductors of wiring or wiring devices.
A circuit breaker is used for protecting the circuits from short circuit and overcurrent. If the conductors of wiring circuit contacts directly, the circuit is cut off by a circuit breaker immediately.
But If the conductors of wiring do not touch directly and the circuit is shorten by an arc current along the carbonized insulating material between the conductors, the short circuit current flows intermittently and the circuit can not be cut off quickly. This current usually exceeds a few hundred Amps because no load except an arc resistance exists in the

circuit. A circuit breaker does not operate until the total energy (integrated square of current) through it reaches its own safety level. This intermittent current often continues for over several minutes.

This phenomena is very likely to cause a fire because of its large and continuous (but intermittent) current. We call this phenomena 'short circuit arcing' for the sake of convenience.

4 Mechanism of intermittent arcing

Figure 1 shows a stranded cord insulated by chloroprene rubber used for the experiments in this study. The cord before the experiment is shown in the upside and the cord after the experiment is shown in the downside. This figure shows the extreme consumption of the cord by short circuit arcing.

Intermittent arcing process is shown in figure 2. (Translation is in the figure.)

a) Arc tracking by a small current

b) Short circuit by a large arc current

c) Explosion of the arc by an extremely large current

Repetition of these process, a), b) and c), makes the current intermittent. Then the larger the current is, the longer the interval of the repetition is.

5 Influence of kind of metals

Influence of the kind of metals on the current was examined by the experimental arrangement shown in figure 3. A pair of metal conductor (2 mm in diameter, 10 mm in length) was put on a synthetic rubber (10 mm x 20 mm x 3 mm in thickness). Copper, brass and iron was used for the conductor. A negligible small resistance (0.01) was used for measuring the current.

At first, an arc tracking is made on the surface of the rubber by hand. The current of this arc tracking is limited by 10 of resistance in series of the tracking. When the switch paralleled with the resistance is turned on, this circuit is shorten by an arc current along the surface of the rubber and the current reaches over a few hundred Amps.

Brass conductor makes the current more intermittent than other metals as shown in figure 4 (a: copper, b: brass, c: iron). This is considered to be due to the melting point of brass which is lower than those of other metals. The longer the interval of the intermittent current is, the longer the time needed to operate the circuit breaker becomes.

6 Protection characteristics by circuit breakers

The short circuit current is varied owing to the resistance of the power source, wiring, arcing itself, and so on. The current was controlled by a variable resistance (0 - 1.15). Stranded cords (30 wires of 0.18 mm in diameter) covered with chloroprene rubber as is shown in figure 1 were used for this experiment because of the high stability and high possibility of arcing.

The interval of intermittent current varies according to the resistance of the circuit as shown in figure 5.

The operating time (from the time of beginning the short circuit to the time of cutting off the current) were measured for various circuit resistance and various types of circuit breakers as shown in table 2. This table shows that the short circuit by arcing, the current of which is below 200 - 300 Amps (peak value), are failed to be protected by the circuit breakers (rated current: 10 A, 15 A).

Table 2

Note 1: Circuit breakers of type A have both electromagnetic mechanism and thermal mechanism for protecting operation. Type B have only thermal mechanism.
Note 2: Each data are average of 5 measurements.
Note 3: '*' means that arcing ended before the operation of the breaker
Note 4: 'infinite' means that the breaker did not operate and arcing continued.
Note 5: The values in ( ) is the maximum peak value of each short circuit current.

Type of	Rated	variable resistance in series with short circuit arcing						
device	current	0.00	0.12	0.23	0.46	0.92	1.15	
Type A	5A	0.007	0.011	0.015	0.017	0.057		seconds
		(346)	(197)	(165)	(139)	(82)	(65)	Amps
Fuse	5A	0.002	0.007	0.016	0.029	0.082	0.116	seconds
		(382)	(238)	(182)	(122)	(76)	(64)	Amps
Type B	10A	0.053*	0.52*	3.84	7.34	23.0	42.8	seconds
		(550)	(325)	(229)	(141)	(90)	(64)	Amps
Type A	15A							seconds
		(450)	(280)	(220)	(130)	(76)	(61)	Amps
Type B	15A	0.142*	6.53	7.66	18.2			seconds
		(474)	(303)	(205)	(136)	---	---	Amps
Fuse	15A	0.009*	0.017*	2.91	0.03			seconds
		(442)	(278)	(208)	(143)	(88)	---	Amps

Operating characteristics (I -t characteristics) of type A (5A) and type B (10A) are shown in figure 6 and 7 respectively. The operating characteristics for the short circuit arcing are shown by the marks, 'o', and the characteristics for the normal short circuit (a direct contact of the conductors) are shown by the mark, 'x' in those figures. These figures show that a short circuit arcing needs longer time to be cut off than a normal short circuit.

7 Influence of the length of wiring

Short circuit arc current was calculated for typical domestic wiring conditions. Internal resistance of power supply and a circuit breaker used in this calculation were 0.12 and 0.01 respectively. Figure 8 and 9 shows the relation between the short circuit arc current (vertical axis) and the length of the cord (horizontal axis) for a stranded cord (50 wires of 0.18 mm in diameter) and a VVF cable (single wire of 1.6 mm in diameter) respectively. Rc is the total resistance of every connections in the circuit.

Figure 8 indicates that if a stranded cord is extended to 10 m long, arc current of a short circuit is decreased to about 200 Amps. It was already mentioned in paragraph 6 that a short circuit by this arc current has a high possibility to be failed in protection.

Figure 9 shows that if the connection resistance, Rc, increased up to 0.2 , arc current of a short circuit is decreased to about 200 Amps. This current also means a high possibility to be failed in protection.

8 Example of short circuit arcing

A pair of metal parts of a plug melted experimentally by a short circuit arcing is shown in figure 10. Similar plugs are sometimes found in actual fire scenes.

A short circuit arcing which occurred in an electrical switch is shown in figure 11. High temperature sparkle and gas blowing from the switch is very likely to ignite combustibles nearby.

Figure 12 shows a stranded cord which caused a disconnection owing to its long use. This cord was found just after ignition and the fire was prevented.

9 Postscript(?) *(This is not conclusion)*

Short circuit arcing was made intentionally in this study. Although insulating materials have been increased their quality, fires are still caused by these failures. It is necessary to doubt about their safety and to make a study on the mechanism of the beginning of short circuit arcing in order to prevent these fires.

16a(9). Fire Hazards of Wiring and Wiring Devices

Y. Hagimoto; Meeting of ??? I.E.E., 1993

(This is a summary of the reports from 7 to 15.)

(Electrical fires related to wiring devices are increasing.)

16b(1) & 17(2). Electrical Discharge and Fire Hazard of a Flexible Cord with a Partial Disconnection

16a: N. Watanabe, Y. Hagimoto; Summary of 1994 National Convention Record I.E.E. Japan

17: N. Watanabe, Y. Hagimoto; Summary of 1994 Annual Meeting of JAFSE

18(2) & 19(1) Difference of Protection Characteristics between Normal-type Circuit Breakers and High-speed-type Circuit Breakers for Short Circuit by Arcing

18: N. Watanabe, Y. Hagimoto, K. Kinoshita; Summary of 1995 Annual Meeting of JAFSE

19: N. Watanabe, Y. Hagimoto, K. Kinoshita; Summary of 1995 National Convention Record I.E.E. Japan

Abstracted by translator

Circuit breakers of two different types were used in this experiment. A breaker of the first type has only a thermal mechanism and is used in almost all the houses in Japan. A breaker of the second type has both thermal mechanism and electromagnetic mechanism and is not popular for its high price.

We showed the latter is effective for the protection of short circuits by arcing in most cases.

20(4). Fire Hazard of Short Circuits on Electrical Wiring

Y. Hagimoto, N. Watanabe, K. Kinoshita; Summary of 1995 Annual Meeting of JAFSE

(Most of the contents of this report is included in No. 1.)

21(2). Effect of Electromagnetic Force on the Arcing Current

Y. Hagimoto, N. Watanabe, K. Kinoshita; Abstract of 1994 Biennial Meeting of Forensic Fire and Explosion Investigation at NIPS Japan

Abstracted by translator

Arcing moves toward load by electromagnetic force of itself. We suppose that this force makes the short-circuit current along carbonised materials intermittent.
(This has an English abstract.)

22 to 24. Interim Report on the Fire Safety of Wiring Devices

(22, 23, 24a: These are not published. But similar report No. 154 is published.)
Abstracted by translator

This study is made by a group of some experts on electrical safety engineering such as fire investigators in police, fire prevention officers in Tokyo Fire Department, public examiners of electrical facilities, electrical engineers in manufacturing companies and so on. This study is still progressing.

Electrical plugs which caused a fire usually have arc marks. Until now, we did not know exactly about the mechanism of arc tracking and the original cause of deterioration of the insulating material.

The purpose of this study is to make it clear what the original cause is, where heat is produced, and where ignition started.

Many plugs just before causing a fire were gathered by public inspectors of electrical facilities. The gathered plugs were divided into two groups according to the place originally heated.

22(1). What we have done, what we are doing now and what we are going to do

(This is just a memo written by my colleague in NRIPS, who is a member of this group.)

1 We have studied on the cause of fire from electrical plugs.

(1) Investigations of actual plugs

Twenty thousands of actual electrical plugs for domestic use were investigated by the public examiners of electrical facilities. Damaged plugs, which did not cause a fire but was likely to cause a fire due to the deterioration of its insulating material (browned(charred), melted, expanded, etc.), were gathered. Damage was mostly found in the plugs used for extension cords. Therefore, most damage of the plugs were considered to be caused by overload.

(2) Examinations and experiments on some typical damaged plugs

Plugs molded with PVC (it is not the plugs fasten with screws) were examined. Plugs covered with uric resin were not examined because they scarcely cause arc tracking. Following matters were examined.

a) X-ray examination (photograph)
b) Electrical resistance at the connection of an electrodes and a conductor of a cord
c) Electrical leakage between the electrodes
d) Thermographical measurement of the temperature at the surface of a plug used in a rated current
e) Same measurement as d), but one side of the insulation of the plug was removed and the measurement was carried out at various current.

This examination results in that the plugs are divided into two groups according to the place originally heated (inside the plug or not).

(3) Origin of the heating

It is considered that the heat which generated inside a plug is caused by a poor connection of an electrode and a conductor of a cord, and that the heat which generated outside a plug may be caused by a poor connection of a plug electrode and a receptacle electrode or by a poor connection in a receptacle. It is also considered that deterioration's of insulating material originated by a leakage current on its moisturized surface are not major causes.

2. Studies on receptacles

Studies on the mechanism of heating related to receptacles are planed to be made by this group. But unfortunately most plugs were not gathered with the receptacles which the plug were connected to.

23(5). Result of the investigation on plugs and receptacles damaged by tracking (Interim Report)

(This report is submitted to the meeting of the group in July 1995 by the Association of Electrical Inspectors in Kanto District (Sorry, I do not know the true name of this association). This is not a published report. Data can not be published without the permission of the group.)

1. Introduction

Our association works for the safety of electrical facilities. Recently Tokyo Fire Department reported in a newspaper that an arc tracking in a wiring device is one of the major causes of domestic electrical fires. So we carried out this investigation to know the actual state of wiring devices.

2. Period of the investigation

1 March 1995 31 March 1995

3. Places investigated

Moist place (in a kitchen, or near a bathroom) which faces to the north

4. Number of investigated devices and damaged devices

(1) Number of investigated devices: 28112

(2) Number of damaged devices: 27

5. Results of investigation

(1) Kinds of damage

Table 1

Kind of damage	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Browning around electrodes of plugs	1 2 4 7 8 10 11 12 14 15 17 18 19 20 22 24 26
Browning between electrodes of plugs	1 4 12 15 22
Bending of electrodes of plugs	2 4 7 10 12 13 18 19 20 24 26
Arcing signs on electrodes of plugs	7 11 12 15 17 20 22 26
Colored electrodes of plugs by overheating	1 2 3 4 6 7 8 10 11 12 15 18 19 20 24 25 26

Charring or melting around holes of receptacles	3 4 6 7 17 18 20
Colored electrodes of receptacles by overheating	3 4 7 18
Poor connections of electrodes and wires by loose screws in plugs of sandwiched type	11 14 17
Poor connections of electrodes and wires in receptacles	18 25
Verdigris	5 13 16 21 23 27
Oily or dusty	6 9

(2) Estimated causes

Table 2

Estimated cause of damage	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Poor connection of plug and receptacle	2 3 4 7 8 10 12 15 18 19 20 26
Poor connection of electrodes and wires in plugs	1 11 14 15 17
Overcurrent	2 4 8 10 18
Verdigris under high humidity	5 13 16 21 23 27
Oil vapour, dust, (moisture?)	6 9 13 22

24(6). Idea of the Interim Report on the Results of Examinations on Electrical Plugs

(This Idea was submitted to the meeting of the group on 22 Nov. 1995 by T. Hijikata who is a researcher/investigator working at the Forensic Science Laboratory in Kanagawa Prefecture Police H.Q.. This is not a published report. Data can not be published without the permission of the group. His latest published report on this subject is translated in No. 154.)

1 3 *(These are not the works he is responsible for.)*

4. Examinations on actual plugs

Remarkably damaged actual plugs found by inspectors were examined.

4.1 Examinations without removement of insulation

4.1.1 Appearances observation

Damaged plugs were used for electrical appliances or extension cords. This type of plugs were covered with molded PVC, and inside of the plugs were also filled with PVC. Other type of plugs were sandwiched by two parts of insulating covers made of uric resin.

Damage of some molded plugs were melting, expanding or browning of insulating material around their electrodes. These damages were found around one or both of electrodes.

Melted marks, which were considered to be caused by poor connection, were observed on the electrodes of a few molded plugs. But any remarkable changes were not observed on the electrodes of other molded plugs.

Most of the damage of sandwiched plugs were browning around their electrodes.

Damaged molded plugs were examined by a) X-ray observation, b) measurement of electrical characteristics, and c) measurement of their surface temperature by a thermo-viewer (infrared video camera) under the condition of rated current. Finally their inside was examined after removing their insulating material. Inside of damaged sandwiched plugs were also examined. Since molded plugs were more damaged than sandwiched plugs, following examinations were made for damaged molded plugs. Results of these examinations are shown in the table below. *(It has no table No..)*

Table *(dated 1995. 12.1)* (1)(5): results of examinations

Sample No.	Rated current (A)	Approval No.	Manufacturer	Load (kW)	(1) Appearance of the damaged insulation around the electrodes	(2)Between electrodes (M)	(3)Inner connection (m)	(4)Another inner connection (m)	(5)Temperature measured with rated current
1	15 A	41-842	MITSUBISHI	1.0	browned around both electrodes	5	1.25	1.082	almost no heat
2	12 A	41-10039	MIKAWA	2.4	melted and expanded around both electrodes		53.44	1.08	67 C
4	15 A	41-5587	?	2.5	browned and expanded around both electrodes		14.21	11.34	56 C
6	15 A	41-9088	NATIONAL	1.34	no sign of heating		1.42	1.42	-
7	12 A	41-5323	NATIONAL	0.9	browned around both electrodes		2.07	5.27	-
8	7 A	41-14834	?	1.0	browned and expanded around both electrodes		6.24	4.09	almost no heat
10	12 A	41-13984	KARASAKI	1.5	melted and expanded around both electrodes		101.02	18.66	75C
12	12 A	41-16342	TSUJI	1.0	browned and expanded around both electrodes	1	1.78	1.74	almost no heat
15	12 A	41-3385	TOSHIBA	?	browned and expanded around both electrodes	5	1.71	1.38	almost no heat
18	?	?	HITACHI	2.0	melted and expanded around both electrodes		-	-	-
19	15 A	41-6173FKD	TOSHIBA	0.6	browned around one of electrodes		2.63	2.58	almost no heat
20	15 A	41-5776	TOSHIBA	1.2	browned around one of electrodes		1.61	1.44	-
22	7A	41-7776	?	0.6	partially sooty		-	-	-
24	7A	41.6152	?	0.7	browned around one of electrodes		5.03	5.97	almost no heat
26	12 A	41-10039	MIKAWA	0.75	browned around one of electrodes		-	-	-

4.1.2 X-ray examination

No failure (disconnection, arc sign, etc.) was found in all samples by X ray.

4.1.3 Electrical leakage measurement between electrodes of plugs

Insulating resistance between electrodes was measured by applying 500V DC. That of sample No. 1, No. 12 and No. 15 was no good (see table). Their insulating material was browned around both electrodes. There was no plugs of bad insulation among the plugs with browning around only one electrode or the plugs with only melting.

4.1.4 Electrical conduction measurement at connections in plugs

Electrical resistance at the connection of the electrode and the wire was calculated from the voltage drop at the connection which was supplied 1A AC. It was noticed that plugs with melted and expanded insulation around their electrodes tend to show higher resistance than the plugs with browned insulation.

4.1.5 Temperature measurement

Rated current was supplied to sample No. 1, 2, 4, 8, 10, 12, 15, 19, 20 and 24 and the temperature on their surface was measured by using thermo-viewer. It was noticed that the plugs of high connection resistance (sample No. 2, 4, 10) generated heat and the plugs of low connection resistance or low insulation resistance did not generate heat.

Conclusion of these examinations are as follows.

1) Plugs, which has high resistance at the connection of their own electrode and their own wire, generate heat inside.

2) The cause of high resistance is considered to be due to oxidation of conductor surface or poor binding at the connections of their electrode and wire.

3), 4), 5) Browning (charring ?) of the insulation material around the electrodes, which was observed in the plugs of low insulating resistance, is considered to be due to heat generation at the poor contact between the electrodes of plugs and receptacles.

24b(8) & 25(2) Static Electricity of Human Body in Walking

24b: Y. Hagimoto, N. Murasaki, M. Matsui, K. Fujibayashi; Meeting of ??? Japan Association for Static Electricity, 25 Feb. 1987 *(I do not know the real name in English)*
25: Y. Hagimoto, M. Murasaki, K. Izumi, S. Chiyoda, M. Matsui, K. Fujibayashi, M. IIzuka; 1987 Annual Meeting of the Institute of Electrostatics Japan
(No. 25 has an English abstract.)

26(2) Increase in Human Body Potential Caused by repeated Movement

Y. Hagimoto, N. Watanabe, K. Kinoshita; 1993 Annual Meeting of the Institute of Electrostatics Japan
(This has an English abstract.)

27(6). Possibility of Gas Explosions Caused by the Electric Sparks of Domestic Switches

Y. Hagimoto, K. Kinoshita, T. Hagiwara, N. Mitsuhashi, J. Shiinoki, R. Sugimoto; Journal of Japan Society for Safety Engineering, Vol. 20, No. 3, 1981

28(6). Ignition Possibility of Inflammable Mixtures with Burning Cigarettes

Y. Hagimoto, K. Kinoshita; J. of Japan Society for Safety Engineering, Vol. 20, No. 4, 1981

29(2). Ignitability of Various Solid Combustibles by Gas Explosion

Y. Hagimoto, K. Kinoshita, T. Hagiwara; Summary of 14th Annual Meeting of Japan Society for Safety Engineering, 1981

30(4). Temperature Measurement of Falling Spatters of Arc Welding

K. Kinoshita, Y. Hagimoto; Summary of 22th Annual Meeting of Japan Society for Safety Engineering, 1989

31(4). Ignitability of Platinum-Benzine Type Pocket Warmer in Hyperbolic Oxygen Chamber

Y. Ishii, Y. Kumooka, Y. Hagimoto, K. Kinoshita; Summary of 1991 Annual Meeting of JAFSE

32(6). When does a Cigarette Cause a Fire ?

Y. Hagimoto; J. or Association of Japan Insurance Companies *(real name?)*, No. 134, 1983

34(10). Studies on the Ignitabiliy of Inflammabls by a Smoldering Cigarette

K. Kinoshita, Y. Hagimoto, M. Tanimoto; NRIPS Report -Forensic Science-, Vol. 41, No. 1, 1988

35(7). Morphological and Chemico-analytical Studies of the Electric Melting Marks

Y. Ishii, S. Seta; NRIPS Report -Forensic Science-, Vol. 29, No. 1, 1976

36(8). Metallurgical Study on the Formation of Melting Marks at the Scene of Fire

Y. Ishii; NRIPS Report -Forensic Science-, Vol. 23, No. 4, 1970
(They have English titles and abstract. But I think I had better make an additional explanation as follows.)

Iron nets was commonly used in a mortar wall in Japan until quite recently. Electricity leaked through the iron net and caused many fires. A couple of bead is formed at the electrical connection of iron wires.

37(9). On The Effect of Thermal Histories upon the Metallographic Structure of Electric Wires

N. Takagi; NRIPS Report -Forensic Science-, Vol. 24, No. 2, 1971
(This has a title and a short abstract written in English.)

38. Research on First and Second Fused Mark Discrimination of Electric Wires (No. 1)

Yoshio ISHIBSHI, Junji KISHIDA
Tokyo Fire Department
Summary of 1990 Annual Meeting of JAFSE

1 Introduction

Bead is a very important evidence to determine the cause or origin of the fire. We distinguish between the bead of primary damage and the bead of secondary damage by observing them with a magnifying glass.

In this study bead wires from actual fire investigations are presented and examined microscopically.

2 Examination and Results

2.1 Examination

(1) Beads for examination

Fifteen beaded wires including primary and secondary beaded wires were collected from actual fire scenes in Tokyo as shown in table 1. Small and definite-cause fires were selected for this examination.

(2) Matters for examination

a) Examination by appearance

What is the kind of the insulating material?

What is the kind of the wire? Conductor is stranded wires or a single wire?

b) Examination by a microscope

Is the surface of the bead rough or smooth?

Are there blowholes on the surface of the bead?

Is the surface glossy or blackit?

c) Examination by SEM

Their surface were observed and photographed.

d) Examination of the inside of the bead

The procedure for examining their inside is as follows.

(i) A bead was buried in resin.

(ii) It was polished by diamond spray up to 1 micron.

(iii) It was exposed to the solution of ammonium hydroxide and hydrogen peroxide.

(iv) Metallographical structure (microstructure) was observed microscopically.

2.2 Results of the examination

(1) Surface of the beads

Distinctive appearance (glossiness, shape and smoothness) of the beads are explained in some literature on fire investigation. But there is no literature where they are explained quantitatively. This is the reason why we observed the actual beads microscopically.

a) Glossiness of surface

Glossiness of the surface of nine primary beads and six secondary beads were examined as shown in figure 1. *(The square Japanese letter means 'figure'.)* There are glossy part, where copper is bared, and black part on the surface of the beads. Vertical axis in figure 1 is the ratio of glossy part and horizontal axis in the same figure is the ratio of black part. The more the ratio of black part is, the larger the angle from vertical axis becomes.

(i) Glossy region (= from 0 to 30)

Seven primary beads and four secondary beads are in this region. Therefore percentage of the number of the primary beads is calculated as 7/9100=77.8% and is plotted in figure 3. Percentage of the number of the secondary beads is also calculated as 4/6100=66.7% and is plotted in figure 3. Percentage of the primary beads is about 11% larger than that of the secondary beads.

(ii) Black region (= from 60 to 90)

No primary bead and one secondary bead are in this region. Percentage of the primary beads is calculated as 0/9100=0% and is plotted in figure 3. Percentage of the number of

the secondary beads is calculated as 1/6100=16.7% and is plotted in figure 3. Percentage of the primary beads is about 17% larger than that of the secondary beads.
(iii) The results mentioned in (i) and (ii) shows that beads can not be discriminated only by these information.

b) Smoothness of the surface

Figure 4 shows the smoothness of the surface. Horizontal axis is the smoothness in appearance. Vertical axis is the number of craters on the surface. The increase of the angle means the increase of roughness of the surface.
(i) Smooth region (= from 0 to 30)
Eight primary beads and five secondary beads are in this region. Therefore percentage of the number of the primary beads is calculated as 8/9100=88.9% and is plotted in figure 5. Percentage of the number of the secondary beads is also calculated as 5/6100=83.3% and is plotted in figure 5. Percentage of the primary beads is about 6% larger than that of the secondary beads.
(ii) Rough region (= from 60 to 90)
One primary bead and one secondary bead are in this region. Therefore percentage of the number of the primary bead is calculated as 1/9100=11.1% and is plotted in figure 5. Percentage of the number of the secondary bead is also calculated as 1/6100=16.7% and is plotted in figure 5. Percentage of the primary bead is about 6% larger than that of the secondary bead.
(iii) The results in (i) and (ii) indicate that the surface of primary beads intend to be smoother than that of secondary beads.

c) Shape of the beads

Beads were classified into three groups according to their shape. Figure 7 and 8 shows the types of primary and secondary beads respectively. Round group, which has the shape shown in the left-hand upside of figure 6, are plotted at the right-hand of the horizontal axis of figure 7 and 8. Hemispheric group, which has the shape shown in the right-hand upside of figure 6, are plotted at the center of the horizontal axis of figure 7 and 8. Other shapes (drop type, long type), shown in the downside of figure 6, are plotted at the left-hand side of the horizontal axis of figure 7 and 8. The vertical axis means the number of plots. Dots of primary beads are connected by a solid line and those of secondary beads are connected by a dotted line.
(i) Seven primary beads and two secondary beads were classified into hemispheric group. Percentage of the number of the primary beads is calculated as 7/9100=77.8% and is plotted on a dotted line above the center of horizontal axis in figure 9. That of the secondary beads is also calculated as 2/6100=33.3% and is plotted on a solid line above the center of horizontal axis in figure 9. Then the percentage of the primary beads, which is hemispheric, is about 45% larger than that of the secondary beads.
(ii) One primary bead and three secondary beads were classified into the third group (drop type or long type). The percentage of the number of the primary beads is calculated as 1/9100=11.1% and is plotted on the solid line at the leftside in figure 9. The percentage of that of secondary beads is calculated asa 3/6100=50.0% and is plotted on the dotted line at the leftside in figure 9.
Then the percentage of the seconary beads, which is classified into the last group, is about 39% larger than that of the primary beads.

(iii) Results in (i) and (ii) shows that the beads can not be discriminated only by these information.

(2) Blowholes, voids and something foreign in the beads *(I(Hagimoto) think something foreign means the residue of insulating material or the scale formed on the conductor.)*

The results obtained from the observation of the surface is shown in table 4. This results shows that the observation of blowholes, voids and inclusion of something foreign is supposed to be effective for the discrimination of the beads.

Table 4

No.	Primary or secondary	Blowholes	Voids	Something foreign included
1	p	yes	yes	no
2	p	yes	yes	no
3	p	yes	yes	no
4	p	no	yes	no
5	p	yes	yes	no
6	p	yes	yes	no
7	p	yes	yes	no
8	p	no	yes	yes
9	p	no	yes	no
10	s	no	no	no
11	s	yes	yes	yes
12	s	yes	yes	no
13	s	no	yes	no
14	s	no	no	yes
15	s	no	yes	no

note: 'yes' means that they were observed.

(3) Microscopical observation of the metallographical structure (microstructure) of the inside of beads

The Results of the microscopical observation of the metallographical structure (microstructure) of the inside of the beads are shown in table 5. This results shows the difficulty of the discrimination of the beads by the information about the structure of alpha-solid solution and the possibility of the discrimination of the beads by the information about eutectic crystal (see photo 1 in the report, No. 41) and small crystallized Cu_2O. Secondary beads supposed to contain more remarkable Cu_2O than primary beads because the former are exposed to high temperature for longer period and cooled more quickly than the latter.

Table 5

No. Primary or Alpha-solid Eutectic Proeutectic crystal Production of Cu_2O

	secondary	solution	crystal	of Cu_2O	at about 800 C
1	p	yes	no	no	no
2	p	yes	no	no	no
3	p	yes	no	no	no
4	p	no	yes	yes	no
5	p	yes	no	no	no
6	p	yes	no	no	yes
7	p	yes	no	no	no
8	p	yes	no	no	yes
9	p	-	-	-	-
10	s	yes	no	no	yes
11	s	yes	no	no	yes
12	s	yes	no	no	yes
13	s	yes	no	no	yes
14	s	yes	no	no	yes
15	s	yes	no	no	no

('Eutectic crystal' is the microstructure shown in photo 1 of the report No. 41.)
('Proeutectic crystal' is also called 'Primary crystal' and is shown in photo 2 in No. 41.)

3 Conclusion

(1) Primary beads tend to have more blowholes than secondary beads. This is considered to be due to the difference of the arcing energy and circumstances between primary and secondary beads.
The ratio of producing blowholes on a primary bead is 6/9 (66.7%).
The ratio of producing blowholes on a secondary bead is 2/6 (33.3%).
(2) Primary beads tend to have more voids than secondary beads.
The ratio of producing voids in a primary bead is 9/9 (100%).
The ratio of producing voids in a secondary bead is 4/6 (66.7%).
(3) Secondary beads tend to include something foreign more easily than primary beads. This is considered to be that the secondary beads are formed after the burning of their insulating material.
The ratio of producing inclusion in a primary bead is 1/9 (11.1%).
The ratio of producing inclusion in a secondary bead is 2/6 (33.3%).
(4) Both primary beads and secondary beads tend to produce much alpha-???. The ratio of producing alpha-solid solution in a primary bead is 7/8 (87.5%).
The ratio of producing alpha-solid solution in a secondary bead is 6/6 (100%).
(5) Secondary beads tend to have more copper oxide, Cu_2O, in its alpha-??? than primary beads.
The ratio of generating Cu_2O in alpha-solid solution of a primary bead is 2/8 (25.0%).
The ratio of generating Cu_2O in alpha-solid solution of a secondary bead is 5/6 (83.3%).
(6) One of the primary bead contains proeutectic crystal of Cu_2O and eutectic crystal of Cu-Cu_2O.

(7) Primary beads are glossier than secondary beads. The difference is about 11% as shown in figure 3.
(8) Primary beads are smoother than secondary beads. The difference is about 6% as shown in figure 5.
(9) Primary beads are rounder than secondary beads. The difference is about 45% as shown in figure 9.

38(4), 39(4) & 41(6). Research on First and Second Fused Mark Discrimination of Electric Wires

38: Y. Ishibashi, J. Kishida (Tokyo Fire Department); Summary of 1990 Annual Meeting of JAFSE
39: J. Kishida, Y. Ishibashi; Summary of 1990 Annual Meeting of JAFSE
41: Tokyo Fire Department; Investigation Section; J. or JAFSE, Vol. 42, No. 2 1992
(This has an English title shown above.)
Abstracted by translator
This study on the method of distinguishing the primary beads and secondary beads of electric wires was made by Tokyo Fire Department.
Nine samples of primary beads and six samples of secondary beads collected at different fire scenes were used for the first half of this study.
The following points were examined in the first half, No. 38:
a) Surface of the bead was glossy or not.
b) Shape of the bead was round or not.
c) Ratio of black part to the whole surface of the bead
d) Blowholes were found on the surface of the beads or not.
e) Voids were found inside the bead or not
f) Something foreign is included in the bead or not
g) Microstructure copper oxide
In the second half of this study, No. 39 & 41, primary beads and secondary beads were made experimentally and they were also examined.
(This is translated totally later.)

39. Research on First and Second Fused Mark Discrimination of Electric Wires (No. 2) *(This has just the same contents as following No. 41.)*

J. Kishida, Y.Ishibashi; Summary of 1990 Annual Meeting of JAFSE

41. Research on First and Second Fused Mark Discrimination of Electric Wires

Tokyo Fire Department, Fire Prevention Division, Investigation Section
J. of JAFSE, Vol. 42, No. 2 1992

1 Preface
Fused wires, which is classified into a primary damaged group and a secondary damaged group, are important evidences to investigate fire causes.

Primary and secondary fused wires were made experimentally and were examined on their metallographical structure (microstructure), voids and included carbonized materials.

2 Experimental method of making sample wires

2.1 Matters examined

Wires were fused in air, nitrogen and carbon dioxide and the temperature of those gases were controlled from 800 to 1000 C.

(1) Samples for the examination on metallographical structure (microstructure)

Four kinds of samples (a, b, c and d) were fused under different conditions shown in figure 1(vertical axis is temperature and horizontal axis is time). Making process and purpose of examination are shown in table 1.

Table 1

Sample No.:	a / b
Atmosphere:	Air of normal temperature / 800 C
Beading method:	Electric copper wire of 0.5 mm in diameter was fused by 30A AC. Experimental arrangements used are shown in figure 3.
Purpose:	Examination of the influence of cooling rate on eutectic crystal
Sample No.:	c / d
Atmosphere:	Air of normal temperature / 800 C
Beading method:	Glowing was started at the contact of copper wires of 0.5 mm in diameter under the condition of 6A AC. Experimental arrangements used are shown in figure 3.
Purpose:	Examination of the wire melted by repeated small arcs

(2) Samples for the examination on voids

Various (big or small) voids are formed in the beads. Sample beads shown in table 2 were made in order to examine the mechanism of forming voids and the difference of voids in primary and secondary beads.

Table 2

Sample No.:	A1 / A2 / A3 / A4 / A5 / A6 B1 / B2 / B3 / B4 / B5 / B6 C1 / C2 / C3 / C4 / C5 /C6
Atmosphere:	Air of normal temp./ 200 / 400 / 600 / 800 / 1000 C Nitrogen of normal temp./ 200 / 400 / 600 / 800 / 1000 C Carbon dioxide of normal temp./ 200 / 400 / 600 / 800 / 1000 C
Beading method:	A bare copper wire of 0.4 mm and 0.5 mm in diameter was fused by 30A AC and was cooled rapidly. Experimental arrangement shown in figure 3 was used.

Sample No.: D
Atmosphere: Air of normal temperature
Beading method: A wire of 0.18 mm in diameter covered with insulation was fused by 30A AC after it was exposed to a gas flame.

Sample No.: E
Atmosphere: Air of normal temperature
Beading method: 200 times of electric sparks (0.33 A) were generated between two fused wires of 0.18 mm in diameter.

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(3) Samples for the examination on carbonized material included

For the discrimination of primary and secondary beads (fused wires), it is important to know whether the beads include carbonized insulating material or not.

Sample beads made under the following three different conditions were examined on their inclusion of carbonized material.

(i) A stranded cord, the element of stranded wires were cut as shown in figure 2, was fused by 9A AC in air of normal temperature.

(ii) A stranded cord shown in figure 2 was fused by 9A AC in air of 600 C.

(iii) A stranded cord was fused by 30A AC after it was exposed to a gas flame.

2.2 Experimental method

Fused wires of 0.18 - 0.5 mm in diameter were used for these examinations. Melted wires by glowing was also used.

(1) Experimental apparatus

Experimental arrangement for fusing a wire is shown in figure 3. A sample wire cut to the length of 100 150 mm was connected to the electrodes A and B at the center of the electric heater. Temperature in the heater was controlled by a transformer. Gas was supplied from one side of the heater.

Experimental arrangement for making a glow is shown in figure 4. The contact of the wire was vibrated automatically. This circuit was also available in the heater shown in figure 3.

3 Results of examinations

3.1 Metallographic structure

The results of metallographical examinations are shown in table 3. Small eutectic crystal filling whole part of the bead was observed when a wire was fused in air and cooled rapidly. Proeutectic crystal of copper was observed when it was fused in air of 800 C an cooled slowly.

Table 3

Sample: No. a
Beading method: A wire of 0.5 mm in diameter was fused in air of normal temperature. It was cooled rapidly in air.
Result of observation: Whole part of the bead was filled with small eutectic crystal as shown in photo 1. Proeutectic crystal of copper was not observed.

Remarks: It is considered that the bead did not form proeutectic crystal because it was cooled rapidly.

Sample No. b

Beading method: A wire of 0.5 mm in diameter was fused in air of 800 C and cooled slowly.

Result of observation: Matrix except proeutectic crystal of copper formed eutectic crystal and proeutectic crystal of copper are observed as shown in photo 2.

Remarks: Proeutectic crystal of copper was formed because of the low cooling rate (cooled slowly). Cu_2O was detected on the outside surface of the bead and on the inside surface of the voids.

Sample: No. c

Beading method: A glow was made at the contact of wires(0.5 mm in diameter) in air of normal temperature. The wires were cooled rapidly in air.

Result of observation: Melted part was very small. Most area of the part was re-crystallized part which was made large by the heat as shown in photo 3. No eutectic crystal was observed.

Remarks: Surface of the beads was oxidized remarkably by small arcs and eroded.

Sample: No. d

Beading of observation: A glow was made at the contact of wires(0.5 mm in diameter). They were cooled in air rapidly.

Result of observation: Melted part was very small as shown in photo 4. The structure of melted part by glowing was different from the melted part by arcing such as sample No. a and b.

Remarks: Surface of the beads was much more oxidized than sample No. c. This indicates the temperature circumstance accelerates the oxidation.

3.2 Voids

Voids were observed microscopically in the beads of wires fused in air. But almost no voids were observed in the beads of wires fused in nitrogen or carbon dioxide.

Visible voids were formed in the beads of wires fused in air of 1000 C. But almost no visible voids were formed in the beads of wires fused in nitrogen or carbon dioxide of 1000 C.

These results shows that the voids results from the reaction of melted copper and oxygen in air. In other word, oxygen is absorbed in melted copper and is separated when the copper is cooled.

Oxygen is absorbed at the surface of the melted beads and the heat in the beads are radiated from their surface. Therefore, primary beads tend to form small voids near the surface because they are usually cooled more rapidly than secondary beads. On the other hand, voids in secondary beads tend to gather and become larger in the deeper area of the beads because they are usually cooled more slowly than primary beads.

Sample No. D in table 2 is shown in Photo 5. This sample was made by fusing in air after exposing to a gas flame as shown in table 2 in order to simulate a secondary bead. A large void was observed at center of the bead.

Sample No. E in table 2 is shown in Photo 6. This sample was made by exposing to sparks after fusing as shown in table 2 in order to simulate a primary bead. Many small voids were observed below the surface.

3.3 Carbonized insulating material included in the beads

No carbonized materials were observed in the beads simulating primary beads. Carbon was detected in the beads simulating secondary beads.

4 Results

(1) Examination on (eutectic crystal of copper and copper oxide) and (the growth of proeutectic crystal) is useful for the discrimination of primary and secondary beads. Supposing that a primary bead is formed at normal temperature and a secondary bead is formed at high temperature, a primary bead tends to be filled with small eutectic crystal but with proeutectic crystal of copper. And a secondary bead tends to form proeutectic crystal of copper before forming eutectic crystal.

(2) In a bead after glowing only re-crystallized part, which was made large by heat, was observed and melted part was very small.

Remarkable oxidation and erosion were observed on the surface of the bead.

(3) It was confirmed experimentally that voids are made by the reaction of melted copper and oxygen in air.

(4) It was confirmed that a primary bead tends to form small voids near the surface of it and a secondary bead tends to form large voids near the center of it.

(5) It was confirmed experimentally that a bead includes carbonized insulation materials which was in contact with the wire before arcing. It was concluded that a secondary bead tends to include more carbonized materials than a primary bead.

5 Conclusion

Examination on the eutectic crystal and proeutectic crystal of copper is useful for the discrimination of primary and secondary wires because they are related to cooling rate.

Primary beads and secondary beads have different features of voids and surface condition. Therefore, it was found that if their metallographical structure (microstructure) and included carbon were also examined, they could be discriminated in high probability. *(Hagimoto think this Japanese word, 'high probability', means no definite value.)*

The number of samples in this study was not so many that we need more examinations for the descrimination in higher probability.

Thanks for the great direction and assistance given by:

Mr M. Ito, Mr. T. Nagai, Mr. K. Saito (Hitachi Co., Ltd.),
Dr. M. Masui (Ibaraki University),
Mr. K. Yoshida and Mr. M. Ohnuki (Hitachi Electric Cable Co., Ltd.).

(Y. Ishibashi is responsible for this report.)

('Mr. or Dr.' are not shown in Japanese sentence. But I know Dr. Masui has 'Dr.'
I do not know the name of the company exactly.)

42(7). Discrimination between Primary and Secondary Ark Marks on Electric Wires by the micro-void Distribution

Nobuo Mitsuhashi (Criminal Investigation Laboratory, Kagawa Pref. Police H.Q.)
NRIPS Report - Forensic Science -, Vol. 48, No. 1, 1995

(All of original figures and tables are written in English.)

Abstracts

When the short circuits was supposed to be he case of a fire, arc marks of electric wires which were picked out from the scene of the fire were very important clue to judge the time of electric accidents. So in order to clarify the micro-voids distribution originated from short circuits, the arc marks formed several experimental conditions were observed with SEM. It indicates that the arc marks of electric wires heated after melting (Primary marks) are different from those melted after heating (Secondary marks) in the distribution of micro-voids whose size are 0.5 - 1.09 m in diameter.

1. Preface

Electrical wires are melted by both the heat of fire and the heat of electrical arcing. Electrical arc marks are classified into two groups. Arc marks in the first group are formed by the arcing which caused the fires and arc marks in the second group are the result of the fires.(ref. 1)

It is said that the discrimination of these marks by their appearance and metallographical structure is difficult because both of them are made by electrical arcing.(ref. 2,3,4)

As the temperature of the wires melted by arcing reaches very high and the wires become to absorb the gases easily.(ref. 5) Then the arc marks are expected to contain micro-voids. Many micro-voids are observed in the arc marks collected in the actual fire scene or made by experimentally.(ref. 4)

Micro-voids in arc marks are affected not only by the circumstances but also by the strength of arcing.

Primary and secondary arc marks were made experimentally by arcing, the current of which was twice as large as the rated current of the circuit beaker. The size and number of micro-voids in the arc marks were examined statistically. The possibility of the discrimination of the marks is presented.

2. Experiments

(1) Method of making arc marks

Stranded cord (area of the cross section: 0.75 mm^2, rated current: 7 Amps) were used in these experiments.

Figure 1 shows the circuit configuration for making arc marks. Electrode A is a graphite bar and electrode B is a copper wire where an arc mark will be made. The graphite electrode is used to simulate the carbonization of the insulating material. Arcing can be caused easily by the use of this electrode.(ref. 6)

Usually a short circuit causes a very large arc current. But in this experiment arc current was limited by a load in the circuit. Electric energy of arcing was controlled by a transformer. The electric energy of arcing was calculated from voltage value and current value measured by digital storage scope.

a) Method of making primary marks

At first ark marks were made by the method shown in figure 1.

Next they were put in a electrical heater and heated to 400, 600, 800 or 1000 C. One minutes later they were taken out of the heater and cooled in the air. The increasing rate of the temperature was 30 C / minutes. They were tested to be kept in the heater for 10 and 30 minutes. But there was no difference in the distribution of micro-voids.

b) Method of making secondary marks

At first stranded cords, which was removed their insulating material carefully, was heated in the same condition as is mentioned above. After cooled, they were covered with their insulating material carefully again.

Next they were used to make ark marks by the method shown in figure 1.

(2) Microscopical observation of metallographical structure of the arc marks

Melted part and non-melted part are needed to be distinguished for the measurement of the distribution of micro-voids. Metallographical structure of the arc marks were observed microscopically and it was confirmed that those parts were distinguished clearly.

(3) Observation of micro-voids by SEM

Micro-voids of 0.5 - 1.0 mm in diameter were counted at three area(54 36 m) near the center of the melted part with SEM respectively and their average were used for this study.

Four groups of ark marks were prepared for this observation.

GROUP 1 (43 samples): Arc marks of electric wires heated after melting
(Primary marks)

GROUP 2 (23 samples): Arc marks of electric wires melted after heating
(Secondary marks)

GROUP 3 (49 samples): Heated electric wires

GROUP 4 (73 samples): Arc marks of electric wires

3. Results of the experiments

The counted number of the micro-voids are shown in table 1. These are normalised by total number, n_i, and shown in figure 2.

Examples of spark discharge energy are shown in table 2. These discharge were arc discharge as shown in figure 3. Arc energy were 2 18 J. This difference of arc energy did not affect the distribution of the micro-voids.

Microstructures (optical microscopic photo) and micro-voids (SEM photo) in three samples heated at different temperature are shown in figure 4. The size of the microstructure became larger as the temperature increased.

The number of micro-voids in four samples heated at different temperature are shown in table 3. The number of micro-voids did not changed as the temperature increased.

Examples of SEM photo of micro-voids of group 1 and group 2 are shown in figure 5. It is observed that group 2 tends to have more micro-voids than group 3.

4. Discussion

(Since this part contains many technical words in statistics field, I can not translate it into English.)

In short, the number of micro-voids of group 1 and group 2 were analyzed statistically. And it was shown that they have statistic difference.

Although arc marks in group 2 were melted in the normal temperature, they are supposed to be similar to actual secondary marks. This is because:

a) Temperature of heating did not affect the number of micro-voids.

b) Arc current is limited.

c) Temperature of heating is lower than the melting point of copper.

If heating and arcing happened closely in time, it sometimes becomes difficult to discriminate group 1. Even if in this case, it is supposed to be possible to discriminate group 2 when the number of micro-voids in melted part is more than twice as many as that in non-melted part.

5. Conclusion

The possibility to discriminate primary marks and secondary marks by the number of micro-voids was shown statistically. But arc marks were made on stranded cord with limited current. It is necessary to examine more arc marks made in various conditions.

43(2). Possibility of Carbon Inclusion in the Molten Mark of Polyvinyl Chloride Insulated Codes Due to a Fire

M. Masui; T. IEE Japan, Vol. 112-A, No. 1, 1992

(This has an English title above shown.)

Abstracted by translator

Stranded cords were used in this experiments. Two different types of arc marks were made experimentally. The author calls them a primary mark and a secondary mark. But I think they does not represent primary and secondary exactly.

Stranded thin wires in the cord were cut by a knife except only one wire left. A large current was supplied to the left thin wire and it melted. This is the way making the first type of arc marks.

In order to make the second type of arc marks, a stranded cord, which was cut as above mentioned, was placed in the gas flame until the insulating material burnt away. After the cord is cooled to normal temperature, a large current was supplied to it to melt the left thin wire.

They were analysed by XMA. The second type of marks included a mass of carbonised material inside.

No. 44 No. 45 No. 52

44(1). Firing Phenomena of Polyvinyl Covering Cords Caused by High Temperature Deterioration

M. Nagata, Y. Yokoi (Tokushima University)
T. IEE Japan, Vol. 103-A, No. 12, 1983

(This has an English title above shown. Content of this report is included in No. 52.)

Abstracted by translator

At first samples of PVC covering were preheated for 60 minutes. Samples preheated to 200 C, samples preheated to 300 C and samples without preheating were used. Electrical resistance and ignition time of the samples placed in various high temperature were measured. The resistance showed unusual patterns. Preheated samples ignited as soon as they were connected to the power source. Samples without preheating ignited within about 10^4 seconds. These results suggest that PVC covering cord might be the cause of the fire if a small part of it is heated to high temperature.

Translation begins here

It is reported that a flexible stranded cord used for a domestic appliance sometimes causes a fire.(ref. 1, 2) It is considered that those fires are caused by the overheating of the remaining wire between the disconnected stranded wires (ref. 3) or the self-heating of PVC covering due to semiconducting characteristics under high temperature (ref. 4). The results of the examination on firing phenomena of PVC covering cords caused by high temperature deterioration are reported.

Configurations of the model polyvinyl chloride covering cord, all element wires and the electrodes used for this examination are shown in figure 1. All element wires (0.18 mm 50) in the cord were removed. Two places (distance = 10 mm) of covering was wound by thin copper wires three time each. The winding wires were used as electrodes for measuring the electrical resistance of the PVC covering. This PVC covering was supported by five ceramic tubes to prevent its flow at high temperature. This PVC covering was settled in an electric heater. A K-type thermocouple was put into the covering for temperature measurement. PVC coverings were exposed to various temperatures for 60 minutes and their electrical resistance were measured at the new temperature.

DC 100V was applied to the electrodes and variations of resistance of the PVC covering with temperature rise (rising rate 6C/min) were measured. The results of this measurement are shown in figure 2. When the PVC covering was heated at about 300 C, its resistance was reduced to the order of 10^6 which means the electric resistivity of 10^2 m. The value of this resistance means that the PVC covering has become semiconducting.

Peaks in these curves were not observed when the PVC coverings were preheated over about 200 C. This reason is considered to be owing to the change of the composition of PVC.

Firing times for various temperatures were also measured. As an actual PVC covering is about 1 mm in thickness, the distance of the electrodes was adjusted to 1 mm and AC 100V was applied to these electrodes. The results of this measurement is shown in figure 3. The PVC coverings preheated at 200 and 300 C were ignited immediately. Although the reason of this immediate ignition is still under consideration, it is concluded that PVC covering, even if it is not preheated, has the possibility to be ignited at high temperature.

Fig. 1. Configurations of model polyvinyl chloride covering cord and electrodes.

Vertical axis: Electrical resistance () (sorry, scale is too small to read.)
Horizontal axis: Temperature (C) (scale is 100, 200 and 300 C)
Line in the right: Not preheated

Line in the center: Preheated at 150 C
Line in the left: Preheated at 170 C

Fig. 2. Variations of resistance of polyvinyl chloride covering with temperature rise (applied voltage DC 100V).

Vertical axis: Time (s)
Horizontal axis: Temperature (C)
Round marks: Not preheated
Triangular marks: Preheated at 200 C
Square marks: Preheated at 300 C

Fig. 3. Relation between firing times and test temperatures (applied voltage AC 100 V).

45(1). Thermal Runaway of Polyvinyl Chloride Covering Cords Caused by High Temperature Deterioration.

M. Nagata (Tokushima University)
T. IEE Japan, Vol. 104-A, No. 3, 1984

(This has an English title above shown. Content of this report is included in No.52.)
Abstracted by translator
In the previous report, No. 44, the author confirmed that PVC shows semiconductive characteristics when they are heated to a few hundred degrees centigrade. In this report, theory of thermistor is applied to calculate the electrical characteristics of PVC. The calculated results showed the possibility of thermal runaway.

Translation begins here

It is already reported that the conductivity of the PVC covering of a stranded cord increases up to about 10^{-4} $^{-1}$cm^{-1}) and the covering shows semiconducting characteristics when it is heated to a few hundred degrees C (ref. 1). Thermal runaway of PVC covering, which results in fire, is expected under some specified condition of resistance, temperature and applied voltage. In this report, theory of thermistor is applied to calculate the electrical characteristics of PVC covering.

The conductivity of PVC covering was measured in the same method used in the previous reports (ref. 1, 2) and the results are shown in figure 1. As the temperature rises higher, the conductivity increased larger. The condutivity reaches about 10^{2} $^{-1}$cm^{-1}) as the temperature reaches infinity. (The conductivity at the infinite temperature is given by extending the lines.)

Vertical axis: Conductivity
Horizontal axis: Temperature
Round marks: Preheated at 200 C
Square marks: Preheated at 300 C
Triangular marks: Preheated at 400 C

Fig. 1. Temperature dependence of electric conductivity for PVC covering with

different thermal treatment temperatures.

In general, conductivity (for DC) of most non-crystallized solid *(molecule of which is jointed by holding same electrons in common ------ Sorry, I do not know this technical term)* is given by:

Eq. (1).(1)

where $_0$, the conductivity at infinite temperature, is known to be about 10^2 5 10^3 $^{-1}$cm^{-1} (ref. 3). Figure 2 gives $_0$ = 10^2 $^{-1}$cm^{-1}, which is within this range, was used in the calculation of equation (1). And is Bortzman (?) constant, T is temperature (K) and E is activation energy (?) related to electrical conduction.

General thermister theory gives the relation of applied voltage E , current I, resistance R and power dissipation P as:

Eq.(2), (3), (4) and (5)

where B = E / 2

where E 1.41 eV (preheated at 400 deg. C)

then B 1.41 1.6 10^{-19} J/2 1.38 10^{-23} J/K 8180 K

, a coefficient of radiation, C, is assumed as:

C = 1 mW/deg.(ref. 4)

, Ta is surrounding temperature

and Ra is the resistance at Ta.

Relationship between applied voltage and current for PVC covering of treatment temperature 400C shown in figure 2 is derived from the equation (2) (5). These V-I characteristics become negative in the range of large current. For example, PVC covering preheated at 400 C shows negative resistance when the applied voltage exceeds 100 V under the surrounding temperature of 50 C.

The possibility of firing by 'thermal runaway' is supported by the experiments in the previous reports (ref. 1).

46(1). Firing Current Range of Model Polyvinyl Chloride Covered Cord Having Disconnected Element Wires

M. Nagata*, Y. Yokoi**, K. Isaka**
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T. IEE Japan, Vol. 102-B, No. 8, 1982

Abstracted by translator

Stranded cords covered with PVC were used in this study. The element wires of the cord were cut by a knife except only one thin wire as shown in figure 1. In the previous report (see No. 51) it was concluded that arcing , which is generated between fused wires, ignites PVC cover when the cover is preheated over 100 C before the arcing and the temperature of the cover exceeds about 550 C during the arcing. In this report, firing current range, which is shown in figure 2, was obtained experimentally.

Translation begins here

Stranded cords with PVC insulation are very commonly used for various electrical appliances because of their good quality in mechanical and electrical characteristics. But some of the troubles of electrical appliances are due to the disconnection of these cords. It is reported that the disconnection of stranded cord may cause a fire even if the current is not in excess of the rating of the protective devices(ref. 1). In this report, firing current range of model PVC cord, which has disconnected element wires except only one element wire as is shown in figure 1, was examined.

Stranded cords, which has 50 element wires of 0.18 mm in diameter, was used for this examination. Insulation of the cord was cut by a knife and element wires inside were configured as the model cord shown in figure 1 and the slash of the insulation was wrapped in a PVC tape. It is already known that ignition depends on the condition whether the temperature of the PVC insulation exceeds 100 C at the moment of fusing of the left wire or not (ref. 2).

The relations of the fusing time to the current obtained in this study are shown in figure 2. The parameter, which was varied from 0.6 cm to 1.4 cm, in figure 2 is the length of the lacked wires. Ten experiments were made in various conditions of the same length and the same current. Figure 2 shows the results of the each condition when the ignition ratio exceeds 10%.

The range of ignition time was 50 1000 seconds. The longer the length of the lacked wire was, the less current was needed for the ignition. The maximum rate of the ignition was 80 %, and the minimum rate of the ignition was 10 or 20 % at the upper limit or at the lower limit of the ignition time. It is considered that the insulation was not ignited in the region under the lower limits of ignition time because the temperature of the insulation had not reached 100 C.

In the region of small currents and over the upper time limits, the left wire was scarcely fused. And if it fused, the temperature of the insulation was not high enough to ignite it.

It was found that the ignition occurs under some specific conditions of ignition time and current. The stranded cords with PVC insulation were ignited when the temperature of their insulation exceed 100 C at the moment of fusing of a left wire and the heat of the fusing increased the temperature of the insulation over 500 C (ref. 2) finally.

(Received March 25, 1982)

47(8). Ignitability of VVF Cable in Contact with Grounded Object

K. Kinoshita, T. Hagiwara, ?. Kinbara; J. or JAFSE, Vol. 28, No. 3, 1978

Abstracted by translator

A flat type polyvinyl chloride sheathed cable shown in figure 1, which we call a VVF cable in Japan, was used in this study.

a) Experiment 1

Insulating material of the cable was removed for about 1 cm. The conductor of the cable was made contact with a galvanised iron plate, which is used for a simple roof. Arcing ignited the insulating PVC most easily when the leakage current was 5 Amps.

b) Experiment 2

Rainwater was dropped on the crack of 1 or 2 mm in width made on the insulation of the cable. A galvanised iron plate colored by paint was also used in this experiment. The colored plate generated arcing breakdown more easily than the normal galvanised iron plate.

Figure 8 and figure 9 show EDX of the surface of colored plate and normal plate before experiment respectively.
Figure 10 and figure 11 show EDX of the surface of colored plate and normal plate after experiment respectively.

48(9). Igniting Process of VVF Cable in Contact with Grounded Object

K. Kikuchi, ?. Kawamura, F. Noto; J. of JAFSE, Vol. 31, No. 3, 1981

Abstracted by translator

Insulating material (PVC) was removed as shown in figure 2. The conductor of the cable was made contact with a grounded galvanised iron plate 44 times a minutes automatically.

Following matters were examined.

a) Igniting process of VVF cable

Igniting process was classified into 6 modes as shown in figure 4.

In 1 mode the conductor and the plate contacted permanently.

In 2 modes cables did not result in ignition.

In 3 modes cables resulted in ignition.

b) Grounded current (5 - 15 Amps) and igniting time

Their relation is shown in figure 10.

c) X-ray diffraction of carbonized insulating materials

A, B and S shown in figure 11 are the X-ray diffraction of the carbonized insulating material of the samples. S shown in figure 11 is the X-ray diffraction of pure graphite. Existence of graphite in the samples was not observed.

d) Chemical reaction

Calcium chloride is generated from the insulating material and will accelerate the arc tracking.

49(4). Partial Disconnection Test of New Product (Stranded Cords Used for Domestic Plugs)

S. Katayama, S. Endo, K. Okumura, N. Fujio, S. Wakita; Summary of 11th Symposium on Safety Engineering, 1981

Abstracted by translator

This report is written by the employee of the company manufacturing electrical cables. They used three types of their new products and two types of their present products for these tests. They showed that their new products had a better property in the bending test than the other products (see table 1, 3). Oxygen ??? of every product shown in table 4 was larger than 27 %, which is the lower border of the fire retardant or self-extinguishing products. This fire retardant property was seemed to have no relation with the actual ignition possibility. It is concluded that the ignitability of the plugs is the result of the various process caused by arcing.

50(11). Why is an Electrical Cord Fixed to a Fuel Hose of a Heating Equipment Often Cut?

Abstracted by translator

This is a summary of discussion on the theme, "why and how electrical stranded cords are cut?" This theme was discussed by the technical committee which belongs to the Japan Oil Heater Inspection Society *(I do not know the real name in English)*. The major matters discussed on are as follows:
1) One stranded cord was fixed in parallel with a fuel hose of an oil heater and whole part of them was bandaged by a PVC tape tightly. The other stranded cord in parallel with a fuel hose was partially bandaged by a PVC tape. After a bending test, the latter caused kink and was cut finally. This is considered to be the result of the large friction between element wires and PVC covering.
2) Stranded cords tend to be cut at high temperature because the radius of the corner made by bending become small due to the flexibility of PVC covering.

51(9). Ignition Experiments and Thermodynamical Analysis of Model Cord with Disconnected Element Wires

N. Mitsuhasi*, Y. Yokoi**, M. Nagata**, K. Isaka**
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** Faculty of Engineering, Tokushima Univ.
J. of JAFSE, Vol. 31, No. 1, 1981

Abstracted by translator
Stranded cords covered with PVC, the conductor of which was cut by a knife except only one thin wire as shown in figure 1, were used in this study. This cord is commonly used for domestic appliances.
1) Bending tests
Bending tests were carried out for this cord automatically. The result of these tests showed that the cords were disconnected completely when the gap of the disconnection was in excess of 5 mm.
2) Ignition experiments of model disconnected cords
Experimental arrangement is shown in figure 7. Current was controlled from 5 to 30 Amps by a variable resistance.
Temperature at the surface of the insulation was measured by a K-type thermocouple of 0.5 mm in diameter. Model cords ignited when the surface temperature was in excess of 100 C as shown in figure 9. It was considered that the insulation (PVC) of the disconnected cords will be ignited when the insulation is preheated to over 100 C before the melting of the single wire which connects the disconnected wires.
E1 and E2 shown in table 1 is the electrical energy dissipate at the disconnection before arcing and during arcing respectively. It is supposed that arcing is not needed for the ignition because E1 is much larger than E2.
3) Calculation of temperature distribution along the wire only which connect the disconnected conductors
Temperature at the center of the disconnection was calculated as shown in figure 12.
Temperature distribution along the cords was calculated as shown in figure 13. This temperature distribution indicates the originally ignited area is narrow.

Translation begins here

Stranded cords covered with PVC are commonly used for various electrical appliances. Electrical failures of the appliances are resulted from the disconnection of the element wires of the cords. It was reported that an actual fire was supposed be caused by the disconnected wires of a stranded cord.

Ignition mechanism of a stranded cord was examined experimentally by using a model cord and considered mathematically. It was confirmed that the insulating PVC was ignited by the heat generated at the left single element wire between disconnected other element wires. This ignition mechanism is differ from that of a short circuit or that of an arc tracking. It was shown that the heat generated by a current less than rating of typical protection devices was enough to ignite the insulation of the cord.

2. Experiments and results

2.1 Bending tests

Two kinds of stranded cords (0.18 mm 30 wires and 0.18 mm 50 wires) insulated with PVC covering were used for the bending tests. Bending tests were carried out for these cords automatically.

(1) Bending machine

Photo of this automatic bending machine is shown in figure 1 and the structure around the bending point is shown in figure 2. A cord fixed to this machine was pushed by two cylinders A and B toward the right-hand and left-hand in figure 2. The angle of bending was 90 C. The number of bending times was controlled by the circuit shown in figure 3.

(2) Results of bending tests

The relation of the rate of disconnection (= the number of disconnected element wires / the number of whole element wires) to the number of bending times is shown in figure 4. This result shows a rapid progress of disconnection after the beginning of the disconnection.

Completely disconnected cords after bending were tested by applying 5 kV DC between their paralleled two conductors for several minutes and no leakage current was detected.

(3) Disconnection by pulling and bending

Figure 5 shows the X-ray photo of disconnected cords by bending, by pulling, by pulling after bending, and repetition of pulling and bending. Every cord was disconnected completely when the gap (which is shown as $2x_0$ in figure 6) of their disconnection was in excess of 5 mm. (This means that the cord might be connected by a few element wires when the gap is shorter than 5 mm.)

(4) Model of a disconnected cord

The structure of the model cord used for ignition experiments is shown in figure 6. It has one element wire which is left between other disconnected wires. The length of the left wire of the model cord was less than 5 mm. The insulation of the cord was cut by a knife and the stranded element wires were removed as shown in figure 6. The insulation was banded with a PVC tape.

2.2 Ignition experiments of model disconnected cords

MCCB (Molded Case Circuit Breaker) rated less than 30 A are commonly used in domestic houses in Japan. They are required to operate within 60 minutes in case of 125 % of rated current and to operate within 2 minutes in case of 200 % of rated current. In the worst case, current of 38 A might flow for one hour in a circuit with MCCB rated 30 A.

In this experiment, the temperature at the surface of the model cord, voltage across the disconnection, and current through the left wires were measured for 5 30 A current. The current was changed by the variable resistor, R_L.

(1) Method of temperature measurement

Temperature at the surface of the insulation was measured by a K-type thermocouple of 0.5 mm in diameter. Figure 7 shows the circuit used for this experiment.

(2) Measurement of the temperature of model cords

Ignition of the insulation of a model cord is affected by the temperature rise before the fusing of the left element wire and the temperature rise caused by the heat of arcing. But it is difficult to measure those traditional temperatures directly. Therefore in order to measure the ignition temperature of the insulation, it was brought in contact with a metal wire which was heated to various temperatures by a gas flame. These measurements showed the ignition temperature of the PVC insulation was about 550 C 10 20 C. The results are shown in figure 8.

(3) Temperature and ignition

It is considered that the ignition of model cord depend upon the total electrical energy (i^2dt) passed through the left element wire. *((i^2dt) does not has the dimension of energy, but is approximately in proportion to the energy.)*

Model cords ignited when the surface temperature was in excess of 100 C as shown in figure 9.

In the region of small current less than 10 A, the insulation of model cords were not ignited because the temperatures of the insulation did not reach 100 C.

In the region of large current, the element wires were fused in several cycles and the temperature rises of the insulation were also not enough to ignite it.

In the region of 10 20 A current, comparatively long periods of heating, which were needed to fuse the element wires, increased the temperature of the insulation more than 100 C. Then the insulation were ignited when the left element wire were fused. Both of the temperature over 100 C and fusing of the left wires were needed for the ignition.

It was considered that the insulation (PVC) of the disconnected cords will be ignited when the insulation is preheated to over 100 C before the fusing of the element wire left between the other disconnected element wires.

(4) Effects of arcing on ignition

When the left element wire were fused, arcing was supposed to be generated. The effects of arcing on the ignition were considered.

Figure 10 shows the voltage wave forms across the disconnection which were measured when the model cords were ignited. T_1 and T_2 are considered to be the beginning of fusing and the ending of fusing respectively. The electrical energy (i^2dt) passed through the left element wire are shown in table 1. E_1 is the energy between the beginning of the experiment (t = 0) and the beginning of the fusing (t = T_1). E_2 is the energy between the beginning of the fusing (t = T_1) and the ending of the fusing (t = T_2).

Table 1 indicates that the energy, E2, was much less than the energy, E1. It is supposed that an arcing is needed only for igniting PVC because E1 is much larger than E2.

2.3 Calculation of temperature distribution along the wire only which connect the disconnected conductors

The following two conditions are necessary for the ignition of model cords:

a) The temperature of the insulation is in excess of 100 C at the beginning of fusing.

b) The temperature of the insulation exceeds 450 C by the heat of arcing after the beginning of fusing.

It was observed that initial ignition occurred in a small area of the insulation and the flame spread to the whole area of the cylindrical insulation. Therefore in order to estimate the initial ignition area which is heated to its ignition point, the temperature distribution along the left element wire was calculated.

(1) Thermal conduction equation (?) of the element wires

The temperature distributions along the left element wire and along the other part of the stranded wires should be calculated separately because of their different diameters.

It is assumed that the heat source g(x) is located at the region $2x_0$ shown in figure 11 and the temperature at the both end of the region is $_1$ (constant). Variables used in the calculation are:

x : Distance from the center of the left element wire

t : Time from the beginning of the current flow (sec)

k : Averaged thermal conductivity of element wire (k = 1.465 10_5 W/mC)

: Density of the element wire (= 8.94 10_3 kg/m_3)

C : Specific heat (C = 0.383 10_3 J/kgC)

K : k/C

d : Diameter of the element wire (m)

S : Cross section area of the element wire (m_2)

I_m : Peak value of the current (A)

: Electrical conductivity of the element wire (= 0.581 10_4 S/m)

Q : I_{m2}/S_2C

$2x_0$: Length of the left element wire (m)

f(x) : Initial temperature distribution

The temperature distribution along the left element wire, W_1(x,t), is given by

W_1/t = K_2W/x_2 + g(x) (1)

(-x_0 x x_0)

and the boundary condition and the initial condition of eq.(1) are

W_1=$_1$ (when x=x_0), and X=f(x) (when t=0) (2)

Solving for W_1 gives

W_1=$_1$+(Q/(2K))(x_{02}-x_2)+$_{m=1}$$A_m$sin(m/(2$x_0$))(x+$x_0$)exp{-K(m/(2$x_0$))$_2$t}

(3)

where

Am=-(Qx_{02}/Km){1+3(-1)$_m$+(8/(m_{22}))(1-(-1)$_m$)}

In a similar way, the temperature distribution along the other part of the wires are given by

W_2=(Q/(2K))$_{B\text{-}B}${(x+2K)$_2$+x_{02}-2x_0(x+2K)}e_{-2}d (4)

(xx_0)

where B=(x_0-x)/(2Kt)

Eq. (4) gives $_1$ in eq. (3) when x=x_0

Temperature at the center of the disconnection was calculated as shown in figure 12. Temperature distribution along the cords was calculated as shown in figure 13. Heat radiation from the surface of the wire was neglected.

The calculated temperature of the left element wire between the disconnected wires did not reach the melting point of copper (about 1083C) when the length of the left element wire, $2x_0$, was short (under about 1 mm) and the range of current was 5 30 A. Actually the wire did not melt in the experiments in these conditions. The calculated temperature of the left element wire between the disconnected wires exceeded the melting point of copper when $2x_0$=3 mm (in case of the current, over 15 A) and $2x_0$=5 mm (in case of the current, over 10 A), and these results were in approximate agreement with the results of actual experiments.

(2) Temperature rise of the insulation

It is supposed that the amount of heat necessary for the insulation to be heated to the temperature over its ignition point is generated before the beginning of fusing. The temperature rise of the insulation caused by this heat is calculated below.

The energy, E_3 ,necessary for the wire to be heated to the melting point, while the wire is solid, is given by

$$E_3=SlC \qquad (5)$$

where S : Cross section area of the wire (m_2)

l : Length (m)

: Density (kg/m_3)

C : Specific heat (J/kgC)

: Temperature difference between room temperature and melting point (C)

Then $E_3 0.473$ J

for the element wire used in these experiments.

On the other hand, The energy, E_4, necessary for the wire to be melted, while the wire is liquid, is given by

$$E_4=Sl \qquad (6)$$

where : Latent heat of fusion of the element wire (=2.0510_5J/kg)

Then $E_4 0.233$ J

Neglecting the energy flow out of the element wire, the total energy, E_0, generated by fusing is given by the sum of E_3 and E_4.

The heat capacity of the insulating PVC, C_0, is given by

$$C_0=S_1 l_1 {}_1 C_1 \qquad (7)$$

where S_1 : Cross section area of the insulation (m_2)

l_1 : Length (m)

$_1$: Density ($_1$=1.4310_3 kg/m_3)

C_1 : Specific heat (C_1=1.6710_3 J/kgC)

Then the temperature rise of the insulation, T, is given by

$$T=E_0/C_0 \qquad (8)$$

The region of the insulation where the temperature exceeds ignition point of PVC is considered below.

a. In case that the cylindrical insulation, which is $2x_0$ long, is heated to the ignition point of PVC from the inside surface to the depth, which is y cm from the inside surface

Assuming that the heat does not conduct the region out of the depth, y, the cross section area, S_1, of the cylindrical insulation, the size of which is 0.5 mm in length and 0.11 cm in diameter, is given by the eq. (7) and the eq. (8) as

$$S_1=(0.11+y)y1.310_{-3}$$

Then $y3.6610_{-3}$ cm

This value, y, is less than about one twenty-second (1/22) of the thickness of the insulation.

b. In case that the cylindrical insulation, which is l_0 cm long, is heated to the ignition point of PVC from the inside surface to the outside surface

In a similar way mentioned above,

$$l_0=l_1 0.13710_{-3} \text{ cm}$$

This value, l_0 ,is less than about 1/3600 of $2x_0$=0.5 cm.

From the results of a and b, the area where the temperature exceeds ignition point of insulation is considered to be very small. Then it is supposed that a small area of the insulation is initially ignited by the heat of fusing and the surrounding area is burnt by the spreading flame. This burning process was observed in the actual experiments.

This ignition mechanism is differ from that of short circuit or arc tracking.

3. Conclusion

A short circuit cause ignition of insulation by its large current. An arc tracking is a result of deterioration of insulation. It is confirmed that the heat generated at the thin wire between disconnected stranded wires is capable to be the ignition source of the insulation of the PVC cord, even if there is no large current and no deterioration of insulation.

The conclusion of this report is as follows.

(1) When a stranded cord is bent repeatedly and the rate of disconnected wires exceeds about 10 %, the rate becomes to increase rapidly.

(2) The insulation of a stranded cord with disconnected wires might be ignited by fusing of the left element wire between the disconnected wires if the insulation is heated to over 100 C before the fusing.

It is supposed that a small area of the insulation is initially ignited by the heat of fusing and the surrounding area is burnt by the spreading flame. This type of ignition can not be protected by protection devices because it can be occur with a normal current.

4. References

(1) J. of Japan Oil Heater Inspection Society *(I do not know the real name in English),* Vol. 2, Feb., Aug., 1974

(2) JIS C8352, C8370, Japan Industrial Standards

(3) M. Nagata, Y. Yokoi; T. IEE Japan, Vol. 93-A, p.285, 1973

(4) Book on mathematics

52(5). Deterioration and Firing Properties of Polyvinyl Chloride Covering Cords at Elevated Temperature

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Bulletin of JAFSE, Vol. 33, No. 2, 1983

(This paper has a following abstract and figures written in English.)
(This literature has an English title and an English abstract. No. 44 and No. 45 are connected into this single report. This report is translated totally later.)

Abstract

The firing phenomena of polyvinyl chloride (PVC) covering cords, having the disconnected element wires, due to an abnormal heating caused by the over current in the residual wires have already been reported by authors.

However, there are different firing causes of the PVC cords, such as the thermal runaway that is produced by the largely reduced electric resistance of the PVC covering at the elevated temperature. It is very important to investigate the firing properties of the PVC cords due to high temperature deterioration since the PVC cords are often used under the condition of the elevated temperature.

In order to determine the relationship between the firing phenomena and high temperature deterioration property of the PVC cords, some experiments and theoretical calculations are carried out using the model PVC covering which has the electrode separation of 10 mm, and is fixing with five porcelain tubes to hold the electrode separation and its configuration the against the deformation at the elevated temperature.

The results obtained from present studies are shown as follows:

(1) The electric resistivity of the PVC covering is reduced to the order of 10_2 (m) with temperature rise of about 300 C from the room temperature, and the PVC covering is changed from the electric insulator into the organic semiconductor.

(2) The thermal runaway of the PVC covering is expected from the theoretical results under the conditions of impressed voltage of AC 100V and the elevated temperature, therefore, the firing phenomena of the PVC cords according to the Kinbara's effect may be caused.

(3) The PVC covering cords, which have been thermally treated at the temperature over 200C, may be fired by applying AC 100V at the room temperature.

1. Introduction

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2. Experimental method

Fig. 1 Schematic diagrams of model PVC cord and its cross section
Fig. 2 Measuring circuit of PVC covering resistance

3. Electric resistance of PVC covering

Electric resistance of PVC coverings, thermal treatment (preheating) of which was non, 150C and 170C, were measured at increasing temperatures (about 6C/min). The results of this measurement is shown in figure 3. As temperature rises, electric resistance of PVC coverings tend to decrease.

These profiles have a small peak at s of profiles at the temperature of 180 280C. The higher the treatment temperature is, the lower the temperature where the small peak appears become.

Electrical resistance is reduced to the order of 10^6 . Electric resistivity of the PVC covering is calculated from this resistance and cross section area of the covering (6.28 10^{-6} m^2). This value of resistivity indicates that the PVC covering is changed into organic semiconductor.

The profiles of electrical resistance of PVC covering which was treated at the temperature over 200 C do not have peaks as shown in figure 4. It is considered that the change of composition which caused the small peaks in figure 3 is already completed during the thermal treatment at the temperature over 200 C, because the peak of 170 C treatment is smaller than that of 150 C treatment.

White smoke including HCl produced from the PVC coverings was observed at the temperature of 180 280 C, and the white smoke decreased remarkably over these temperatures (ref. 4). It is considered that these results indicates the 'activator effect' (?) of Cl separated from PVC coverings which affects the formation of peaks on the profiles (ref. 4). But the change of composition of PVC coverings is not examined yet. It will be examined after this.

Fig. 3 Temperature dependence of electric resistance for PVC covering with thermal treatment temperature(1).

Fig. 4 Temperature dependant of electric resistance for PVC covering with different thermal treatment temperature(2).

4. Thermal runaway

Electrical resistance of PVC coverings decrease when its temperature rises. This decrease of resistance results in increase of current which increase its temperature. Therefore, firing of PVC covering may be caused by the thermal runaway of PVC covering which is expected from the following theoretical consideration (static theory of semiconductor).

Voltage drop E, current I, electrical resistance R and electrical power dissipation P of the model PVC cord are given by:

$$R = R\exp(B/T) = R_a\exp(B/T-B/T_a) \quad (1)$$

$$P = C(T-T_a) \quad (2)$$

$$I = (P/R)1/2 = \{(C/R)(T-T_a)\}1/2$$
$$= \{(C/R_a)(T-T_a)\exp(B/T_a-B/T)\}1/2 \quad (3)$$

$$E = (PR)1/2 = \{CR(T-T_a)\}1/2$$
$$= \{CR_a(T-T_a)\exp(B/T-B/T_a)\}1/2 \quad (4)$$

where B = E / 2

where E 1.41 eV (preheated at 400 deg. C)

then B 1.41 1.6 10^{-19} J/2 1.38 10^{-23} J/K 8180 K

, a coefficient of radiation, C, is assumed as:

C = 1 mW/deg.(ref. 4)

, T_a is surrounding temperature

and R_a is the resistance at T_a.

--------almost same matters are mentioned as in No. 45----------

Fig. 5 Temperature dependence of electric conductivity for PVC covering with different thermal treatment temperatures.

Fig. 6 Relations between applied voltage and current for PVC covering of treatment temperature 400C with different ambient temperatures.

5. Firing of PVC covering

Environmental temperature of PVC cord shown in figure 1 was kept constant (between 20 and 300 C) and various voltage was applied until the minimum voltage necessary to ignite the PVC covering was found. The relation between environmental temperature to minimum ignition voltage is shown in figure 7. As treatment temperature (preheating temperature) was increased, minimum ignition voltage decreased. As environmental temperature was increased, minimum ignition voltage was also decreased. These characteristics are considered to be the result of their increasing conductivity shown in figure 3 and 4.

Although the characteristics shown in figure 7 was obtained for the electrode separation of 10 mm, actual cords have conductors in the separation of about 1 mm. Therefore, the electrode separation in figure 1 was changed to 1 mm and 100V AC was applied to these electrodes. The relation between the ignition time to environmental temperature is shown in figure 8.

PVC coverings with thermal treatment (preheated) at 200C or 300C were ignited immediately under environmental temperature of 20 30 C. This is considered to be due to the decreased breakdown voltage of PVC and movement of the electrodes caused by thermal treatment (preheating).

Even PVC coverings with no thermal treatment (un-preheated) were ignited within a few 10^4 seconds under environmental temperature of about 200C. This result indicates that the PVC covering cords, which have been thermally treated over 200C, may be fired by applying AC 100V at the room temperature.

Fig. 7 Temperature dependence of breakdown voltage for PVC covering with different treatment temperatures.

Fig. 8 Relation between time to fire and temperature for PVC covering by applying AC 100V with different treatment temperatures.

6. Conclusion

The results obtained from present studies on the deterioration and firing properties of polyvinyl chloride covering are shown as follows:

(1) The electric resistivity of the PVC covering is reduced to the order of 10^2 (m) with temperature rise of about 300 C from the room temperature, and the PVC covering is changed from the electric insulator into the organic semiconductor.

(2) The thermal runaway of the PVC covering is expected from the theoretical results under the conditions of impressed voltage of AC 100V and the elevated temperature, therefore, the firing phenomena of the PVC cords according to the Kinbara's effect may be caused.

(3) The PVC covering cords, which have been thermally treated at the temperature over 200C, may be fired by applying AC 100V at the room temperature.

Acknowledgement
References

53a(2). Research on thermal Phenomena of Twist Joint Point of P.V.C. Insulated Flexible Cords

T. Hijikata, A. Ogawara; Summary of 1992 Annual meeting of JAFSE

53b(6). Protection Behavior of MCCB for the Short-circuited Cords and VVF Cables

S. Soma, M. Fujimura, S. Fujimura; J. of JAFSE, Vol. 32, No. 1, 1982

Abstracted by translator

This is an old study reported in 1982. MCCB means a Molded Case Circuit Breaker and is used in most of houses in Japan. They used stranded cords with PVC insulation, which is used for most of domestic appliances, and VVF cables, which is used for the wiring behind wall and ceiling. They showed experimentally that a MCCB does not always operate even if a bead is made in the wiring.

54(5). The Carbonisation and the Degree of Crystallisation of Organic Insulator due to Electric Breakdown

M. Ueyama; NRIPS Report -Forensic Science-, Vol. 28, No. 2, 1975

(This paper has an English title above shown and an English abstract.)

55(8). Experiments on Dielectric Breakdown and Ignition of Phenolic Resin Used in the Battery of DC 24V

M. Matsuura; J. of JAFSE; Vol. 28, No. 3, 1978

A fire occurred in a ferryboat sailing. Investigation of police concluded that the fire was originated by an arc tracking at the electrical terminal of the battery switch of a truck in the ferryboat because the terminal was melted. But the manufacturer of the truck did not agree with this conclusion and requested other experts to investigate the cause of the fire. They carried out experiments and concluded that the arc tracking at the terminal of the battery switch was caused by seawater used as the extinguishant.

56(7). Migration Phenomena of Silver and Copper Electrodes on Surface of Organic Insulating Materials

N. Yoshimura, M. Nishida, S. Fujita, F. Noto; J. of Japan Association for Static Electricity (real name?), Vol. 11, No. 2, 1987

(This paper has an English title above shown and an English abstract.)

57(10). Multiplication Phenomenon of Copper Metallic Compounds Caused by Electrolytic Corrosion and Deterioration of Insulating Materials

K. Kawamura, T. Toshiyuki, S. Sakamoto; Bulletin of JAFSE(Japanese Association for Fire Science and Engineering), Vol. 32, No. 1, 1982

(This paper has an English title above shown and an English abstract.)

59(8). Electric Ignition Phenomena Caused by Tracking Failure in Distribution Cable and Development of Electric Fire Protection Equipment

K. Kawamura, F. Noto, S. Sakamoto; Bulletin of JAFSE, Vol. 31, No. 1, 1981
(This paper has an English title above shown and an English abstract.)

60(6). The Study on Tracking between Blades of Attachment Plug

Tokyo Fire Department, Investigation Section; J. of JAFSE, Vol. 44, No. 6, 1994
(This paper has an English title above shown.)
Abstracted by translator
Japan has approximately 6600 fires a year. About 13 % of them are electrical fires and about 6 % of them are supposed to be related to arc tracking.
a) Insulating material of a plug which caused an actual fire was analyzed by Photoelectron Spectroscopy. The spectrum is shown in figure 1. *(Nothing but the figure 1 is shown about the Photoelectron Spectroscopy.)*
b) Seventeen various pairs of plug and receptacle including worn-out one were put to the test of arc tracking by dropping 3 % NaCl solution, 1 % NH4Cl solution or 1% NH4Cl solution mixed with 5% surfactant. Ten of them resulted in ignition. Uric resin did not cause arc tracking.
c) Four pairs of plug and receptacle were put to the test of exposing to gas fire. Although the insulating material was burnt, metal parts did not melted.

61(4). Influence of the Direction of a Electric Hair Drier on Melting of its Heater

A. Kaizoji; NRIPS Report - Forensic Science-, Vol. 26, No. 2, 1973

62(3). Evidence of Use of an Incandescent Lamp in case of Fire

A. Kaizoji; NRIPS Report -Forensic Science-, Vol. 29, No. 4, 1976

63(4). FIRE REPORT: Fires of Small Battery

Tokyo Fire Department, Fire Investigation Section; J. of JAFSE, Vol. 44, No. 5, 1994

64(5). A Case Report of a Fire Caused by a Down-light and an Experiment for the Proof

M. Mizumoto, Y. Ibata, T. Yamaguchi; J. of JAFSE, Vol. 44, No. 1, 1994
(Down-light(?) is a light on the ceiling as if it sinks into the ceiling.)

65(5). A Case Report of a Malfunction of Electric Leakage Breaker

T. Otsuka, T. Hijikata, M. Hara; J. of JAFSE, Vol. 37, No. 3, 1987

66(8). Fire Hazard of a Television

Abstracted by translator
In the seven years from 1988 to 1994, about 700 cases of fire-hazardous television were reported to the National Living Center. *(I do not know the real English name. This is a public institute.)*

Table Number of reports (claims) to the institute from comsumers on the hazard of their electrical appliances used more than 9 years (reported Oct.1974 May 1991)

	Fire hazard	Others
Television	70	0
Refrigelator	19	20
Electric blanket	16	3
Electric lamp	9	9
Washing machine	15	1
Electric fan	12	4
Flashlight (elecric torch)	11	1
Air conditioner	8	1
Electric shaver	5	1
Japanese electric foot warmer used in a bed	4	0
Japanese electric foot warmer with flame and coverlet	4	0

In 1992, 109 cases of fire hazrardous television were reported to the institute.

Table Fire hazardous televisions which manufacturers appealed repairing

Manufacturer	Type	Manufacturing period	Number of the products	Rate of repaired TV
SHARP(JAPAN)		Apr. 1972 - Jun 1977	340000	21.5%
TOSHIBA(JAPAN)		Sept. 1984 - Feb. 1985	8000	75.1%
PIONEER (JAPAN)		Sept. 1987 - Jul. 1988	10000	96.3%
MATSUSHITA(Panasonic, JAPAN)		Dec. 1981 - Oct. 1982	29000	57.5%
		Nov. 1984 - Jul. 1985	25000	71.9%
SONY(JAPAN)		Feb. 1979 - Sept. 1979	214000	8.3%
		Feb. 1980	42000	42.8%
		Oct. 1984, Apr. 1985, Feb. 1986	137000	52.4%
JASCO?(TAIWAN)		Feb. 1989 - Jan. 1990	2000	20.5%
SANSEI JAPAN(INPORT)		Sept. 1988 - Jun 1989	31000	40.6%
SHARP(JAPAN)		Jun 1986 - Mar. 1988	48000	53.4%

Causes of the failure of TV reported from 1987 to 1991 are as follows:

1) Leakage current from high voltage circuit(46%)
   - High voltage unit (9%)
   - High voltage transformer(37%)
     - Short-circuit between coils in a high voltage transformer
     - Leakage current
       - Deterioration of insulating characteristics at the surface of a transformer
       - Dusty surface of a transformer

2) Poor connection(24%)
   - Crack at a soldered terminal

67a(4). Study on Causes of Fires after Hyogoken-Nanbu Earthquake
Y. Murosaki; Summary of 1995 Annual Meeting of JAFSE
(This report has an English title above shown. This earthquake is the well-known big earthquake in Kobe area in 1995.)

67b(4). Ignition Mechanism of Fuel Leaked in Vehicles
T. Takahashi, M. Sugisaki, T. Sada, T. Tsurumi (Tokyo Fire Department); Summary of 1995 Annual Meeting of JAFSE
(This paper has an English title above shown.)

68(4). Ignition Process of Intermittent Short-circuit on the Modelled Automobile Wires
Y. Tamura, J.Suzuki; Summary of 1995 Annual Meeting of JAFSE
(This paper has an English title above shown.)

69(4). *(This is the same report as shown in No. 20.)*
Y. Hagimoto, N. Watanabe, K. Kinoshita; Summary of 1995 Annual Meeting of JAFSE

70(2). *(This is the same report as shown in No. 18.)*
N. Watanabe, Y. Hagimoto, K. Kinoshita; Summary of 1995 Annual Meeting of JAFSE

71(1) 153(1)
These are the summary of the presentations in the Forensic Science Meeting for Fire and Explosion in 1990, 1992 and 1994 held by the National Research Institute of Police Science in Japan. Each of them has its own English title and English abstract. I picked up the titles which is related to the electrical cause of fire as listed below.

83. A Case Report of Fire Accident by a Color TV Set

84. Fire Hazard of Clothes Dryer

86. Fire Hazard of Plug and Receptacle

87. A Fire of Power Transmission Cable in a Tunnel

89. An Investigation On Measurement Methods of Insulation Resistance

90. Development of Breaker-Operating Computer Simulation Program and Breaking Characteristics between Main Breaker and Branch Breakers

91. Fire Hazards of Short Circuit by Arc Discharge on Carbonized Conductive Track
(Content of this report is included in No. 15.)

92. Thermal Degradation Properties of Electrical PVC Tape

94. Classification of Arc Marks on Electrical Wires

(Content of this report is included in No. 42.)

95. Ignition Hazard by Short Circuit between Element Wires of a Stranded Cord

Y. Nishida
Criminal Investigation Laboratory, Nara Pref. Police H.Q.
NRIPS Reports - Forensic Science -, Vol. 45, No. 4, November 1992
Abstracts of Biennial Meeting of Forensic Fire and Explosion Investigation at NRIPS Japan, 1992

1 Introduction

The author experienced a fire caused by a short-circuit between element wires of a wounded stranded cord. The purpose of this study is to know the mechanism of ignition by a short-circuit between a few thin element wires. The diameter of the element wires used for the experiments is 0.18 mm.

2 Experimental method

(1) The experimental arrangements are shown in figure 1. Two element wires were contacted in various crossing angles. Short-circuit was made at various phase angle by a phase controller. Voltage across the contact and current was measured by a digital storage oscilloscope. Electrical energy generated at the contact was calculated from the voltage and the current.

(2) The wires were put on various combustible materials and their minimum ignition energies were measured. Electrical energy was controlled by the phase controller.

3 Results

(1) The short energy was subdivided into heat energy and following spark energy. Heat energy is the electrical energy caused by the contact resistance. Spark energy is the electrical energy of arcing at the contact. Less contact duty (load ?) between element wires, which pushed the wires each other, made larger spark energy and less heat energy.

(2) Spark energy changed largely according to the phase angle at the beginning of short circuit. On the other hand, heat energy was much affected by the contact duty.

(3) There was a limitation in short energy induced from a couple of single element wire of 0.18 mm in diameter, and it was about 35 joules.

(4) When the number of element wires increased, the period of heat energy increased, which increased the heat energy. But the period of spark energy did not increase, which did not increase the spark energy.

(5) Minimum ignition energy of combustible materials varied with the environment such as humidity and condition of the surface layer of the materials. Minimum ignition energy was 0.3 joules for cotton. Cotton and paper was not ignited by the spark energy but was ignited by the heat energy.

6 Conclusion

It was confirmed that combustible materials such as cotton is easily ignited by the heat of short-circuit between element wires of a stranded cord, although the insulating materials, which is usually PVC, of the stranded cord is rather hard to be ignited by the short-circuit.

96. Studies on Thermal Phenomena of Twisted Joint Point of P.V.C. Insulated Flexible Cords
(Content of this report is included in No. 53.)

97. Electrical Characteristics of Carbonized Electrical Insulating Materials
(Content of this report is included in No. 6.)

125. Dielectric and Electric Conductance Characteristics of Polyvinyl Chloride Exposed to Corona Discharge

126. Tracking Breakdown of Electric Plugs and Receptacles

127. Experiments of Firing by Electric Soldering Iron

128. Fire Accident of Bathroom Ceiling Caused with a Ventilating Drier

129. A Case Report of a Fire Caused by a Desk Lamp with a touch Switch

130. A Case Report of a Fire Accident Started at the Wiring of a Ceramic-type Electric Space Heater

131. A Study on the Fusion of Electric Heating Wire

132. Relationship of Service Entrance Direction to the Arc Signs of Short Circuits
(Content of this report is included in No. 21.)

154. Fire Causes at Electrical Wiring Devices
(Fire Cases and Their Feature, Damage Conditions and Prevention)

T. Hijikata
Scientific Crime Laboratory, Kanagawa Prefecture Police H.Q.
J. of JAFSE, Vol. 46, No. 2(?), 1996

(This report is written by Mr. Hijikata, who is one of the member of the group studying on the matters shown in **No. 22 No. 24***, for the Journal of Japan Association for Fire Science and Technology which will be issued soon.)*

1 Introduction
2 Electrical plugs
2.1 Structure of electrical plugs (photo 1)
Most of electrical plugs are molded-type shown in photo 1. Sandwiched-type plugs *(I do not know the true name. Covers are sandwiched and fixed with a screw.)* are sold for repair use. Covers of sandwiched plugs are made of uric resin.

Molded plugs have crimp connections of electrodes and wires inside and are filled with PVC. Some of the molded plugs have double insulation. Their electrodes are insulated by thermosetting resin such as uric resin, and moreover, they are covered with molded PVC. This type of plugs are used for large power dissipative appliances.

Any plugs, rating of which is 125V and below 15A), have electrodes of same size. Electrodes used for PVC plugs are plated with nickel and electrodes used for uric resin plugs are not plated.

2.2 Fire cases started from electrical plugs

(1) Case 1 (photo 2)

(2) Case 2 (photo 3)

(3) Case 3 (photo 4)

(4) Case 4 (photo 5)

(5) Case 5 (photo 6)

(6) Case 6 (photo 7)

(7) Case 7 (photo 8)

2.3 Features of fire causes at electrical plugs

Molded plugs with PVC insulation, which are used for the power supply cords attached to large power dissipating appliances (0.5 1.5 kW) or which are used for the extension cords supplying overcurrent, tend to cause more fires than other electrical plugs. Arcing between electrodes caused by deterioration of the insulating material tends to leave ark marks near the root of the electrodes. Charred insulating materials around the marks usually have electrical conductivity.

Top of the electrodes of plugs and receptacles are usually not melted.

New type of plugs with double insulation are beginning to be used. Their electrodes are insulated by thermosetting resin such as uric resin, and moreover, they are covered with molded PVC. Fire cases started from this type of plugs are not known yet.

Most of damaged plugs had charring or melting of insulation around the root of the electrodes. These plugs were examined by a) appearance observation, b) electrical leakage test by DC 500V, c) non destructive X-ray examination, d) conductivity test between electrodes and wires, and e) temperature measurement with rated current. After all, conductive track, which causes arc tracking, was not found on the surface of their insulation.

Damaged plugs were classified into two groups. One is the group which has heat source inside. The other is the group which has no heat source inside. The former group of plugs tend to have a large resistance between their electrodes and wires, and tend to be used with overcurrent in excess of rated current. The latter group of plugs were considered to be damaged by the heat generated at the contacts of plugs and receptacles. In this connection, electrodes of molded plugs plated with nickel dose not change their color at the temperature of 150 180 C which is required to start the deterioration of PVC insulation. So PVC insulation is deteriorated by the heat conducting though the electrode without changing their color.

It is supposed that <u>the deterioration of insulation between the electrodes of plugs is not usually caused by the leakage current through the moisturized surface of the insulation but is usually caused by the heat due to poor connections or overcurrent.</u>

More examinations and studies on many actual samples are in progress now. The results of them may be published in the next chance.

3 Damage condition and prevention method

3.1 Using condition (How it was used)

(1) Force

Some of the plugs were resulted from the force pulling the wires of the plugs. It is needed to develop the plugs which come off from receptacles when the pulling force exceeds limit.

(2) Overload

Extension cords are apt to be used under most severe conditions (overcurrent) among the wiring devices. Some of the latest model are equipped with an indicator (LED) of overcurrent (photo 9). Extension cords need to be equipped with this kind of safety devices warming by light or sound.

3.2 Structural problems

(1) Insulating materials of plugs

Although fires caused by arcing at the plugs with PVC insulation are reported, fires caused by arcing at the plugs with uric resin insulation are very rare. Plugs used for large loads are suggested to be insulated by uric resin.

(2) Standards of plugs

Various ratings of plugs, such as 7A, 10A, 12A and 15A, are in use now. But they have the same size of electrodes, so that they can be used with overcurrent. In addition, molded plugs used for large power dissipative appliances are likely to cause more fires than other plugs. Therefore, the rating of plugs are suggested to be reconsidered

(3) Prevention of overload

Some wiring devices, such as a corner-tap which has one inlet and two or three outlets, have receiving electrodes of simple structure. As the electrode hold the corresponding electrode of plugs with a single elastic plate. This type of receptacles are considered to be apt to result in fires due to the poor connection. They are commonly used for the receptacle attached to dressing tables, washbowl tables and so on. Although their rating current are limited to 600W, most of them are actually used with overcurrent. Ratings or structure of these kinds of devices are suggested to be reconsidered.

(4) Connection to wires inside plugs

Partial disconnection of wires and changed color of the wires were observed nearby the crimp connection. This partial disconnection was considered to be caused by the crimping when it was manufactured. Some of element wires starting to be disconnected were observed microscopically. This disconnection is supposed to be prevented by controlling the crimping pressure and soldering the connection.

3.3 Circuit protection

(1) Circuit breaker

Circuit breakers (thermal type, magnetic type or differential type which detect leakage current) for domestic use are used for the circuit protection (from overcurrent and short circuit) and prevention of leakage current. It is difficult for these devices to protect circuits from short circuit by arcing through charred insulation (ref. 1 4). It is suggested to develop a new circuit breaker which can detect the current of such arcing.

(2) Ratings of circuit breakers and electric appliances

Although the maximum rated current of common receptacles is 15 A, the rating of the branch circuit breakers is usually 20 A. This means the possibility that the receptacles are used with 20 A which is 30% over their ratings. It is suggested that the rating of the receptacle should have the same rating as the branch circuit breakers.

3.4 Inspection of wiring devices

Most of the fires originated from electrical plugs are caused by the deterioration of the insulating material resulted from the poor contact of plugs and receptacles or from the overcurrent.

Line-to-line leakage test, line-to-ground leakage test, and observation by appearances are used for the examination of electrical wiring and wiring equipments now. Test of holding pressure at the electrodes of receptacles is suggested to be added to this examination.

4 Conclusion

Electrical fires originated from wiring devices are increasing gradually. It is necessary to reconsider the safety of electricity and to do any prevention possible.

It is surprising that many consumers think "A receptacle can be connected to any load in spite of their rating.", "I do not know the difference between power dissipation and rating current.", or "Circuit breakers can protect any failures of electrical circuits.". Electrical safety for these consumers is needed to be developed.

155(3). Electric Facilities in Houses

156(3). Electric Appliances and Receptacles in Houses

157(2). Circuit Breakers

158(4). Data of New Type Circuit Breakers

159(1). Summary of Fire Causes in Electrical Cords

160(56). Japanese Industrial Standard

C 3306-1987 Polyvinyl Chloride Insulated Flexible Cords

C 8370-1986 Molded Case Circuit Breakers (MCCB)

My idea how to make a continuous arcing

Y. Hagimoto 11. 3. 1996

I think the most important point is to restrict the short-curcuit current within 50 100 A (peak value). If the current exceeds 200 300 A, it is considered to be difficult to continue arcing because of the strong arcing. Strong arcing blows off the carbonized insulation and melted conductors. This makes arcing intermittent.

In order to restrict the short-circuit current to 60 A, about 4 of resistance should be connected in series. This resistance should be about (60 A)^2 4 =14400 W of wattage. This wattage is quite large. So we usually use many large heaters (1 kW(1020)) connected in parallel.

A long cable is also useful as the substitute for this resistance. Resistance of a cable of 0.75 mm^2 in cross section and 100 m in length is about 2.3 . But the temperature of the cable should be taken care, or the insulation will be melted.

Lamps are not suitable for this use because their resistance is quite low before being lighted.